Chapter 9
Cotton

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Abstract Cotton is a significant agricultural commodity throughout the world that is used primarily for its fibers to manufacture textiles, but with notable secondary value for its seeds. As cotton oil mills began to operate and products other than whole cottonseed became available, the value of cottonseed increased. This increase in the value of cottonseed spurred research efforts to improve the protein and oil quantity and quality of cottonseed. This chapter concentrates on several aspects of cotton as an oilseed crop, including seed quality, seed processing, uses of cottonseed, and prospects for future improvement in cottonseed quality. Cottonseed oil and meal are the two most valuable products of cottonseed. Cottonseed oil is considered heart healthy and has a long shelf life. Cottonseed meal is used principally as feed for livestock and its major value is as a concentrated protein supplement. Cottonseed flour has a high quality amino acid profile. A limiting nutritional factor of cottonseed is the presence of gossypol. Gossypol binds with protein causing a lysine deficiency and has toxic effects when ingested by nonruminant animals. Despite this limitation, the seed component of cotton production cannot be ignored, and the production of gossypol-free seed would enhance the overall value of cotton. The industry is beginning to see cottonseed as a viable source of revenue, thereby adding value to each and every acre of cotton.

Keywords Cotton (*Gossypium* spp.) • Cottonseed • Protein and oil quantity • Gossypol • Lysine deficiency • Molecular breeding

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S.K. Gupta (ed.), *Technological Innovations in Major World Oil Crops, Volume 1: Breeding*, DOI 10.1007/978-1-4614-0356-2_9,

1 Introduction

Cotton (*Gossypium* spp.) is a significant agricultural commodity, primarily commercially grown for its fibers, but with secondary value as an oilseed crop. The focus of this chapter is on the value of cotton as an oilseed crop that produces oil and meal for animal and human consumption.

Several thorough reviews have been published telling the history of cotton, including its origin, domestication, and taxonomy. For the most recent review, please consult Hague et al. (2009). There are 49 recognized species of cotton, and four of these species are domesticated: *G. hirsutum* and *G. barbadense* are tetraploids and *G. arboreum* and *G. herbaceum* are diploids. These four domesticated species are cultivated throughout the world between 37°N and 32°S latitude (Hague et al. 2009).

Cotton production, processing, and uses of its raw material (primarily cotton fiber) are detailed in a review by Campbell and Hinze (2010). When cotton leaves a producer's field, it goes to a gin where the seeds are separated from the long cotton fibers. The ginned seeds are then marketed to the cottonseed crushing industry while the fibers are sent to textile manufacturers. Cotton production, seed crushing, and fiber processing are highly mechanized in many countries of the world, and research primarily focuses on improving cotton fiber quality to meet the needs of textile manufacturers and the end-users of textile products. Research on improving cottonseed quality is gaining interest due to the increasing economic value of cottonseed.

The cottonseed is comprised of a kernel (embryo) which contains the oil and protein, and the kernel is surrounded by a hard outer shell (hull). Following ginning, which removes the long fibers, the fuzzy seed is sent to a mill for crushing to extract the oil. One ton of cottonseed will yield approximately 145 kg oil, 245 kg hulls, 413 kg meal, 76 kg short fibers that remain after ginning, and 29 kg waste products lost during processing.

In this chapter, we will discuss several measures of cottonseed that are used to assess its quality. We will discuss how cottonseed is processed to obtain oil and protein. We will also consider the effect of gossypol and the limitations it presents when using cottonseed as a source of protein and oil for humans and animals.

2 Cottonseed Quality

Relative to lint yield and quality improvement programs, few research efforts have been directed towards improving cottonseed quality. Cottonseed quality was the focus of research efforts in the 1970s and 1980s. Following this period, interest in cottonseed quality waned until recent times. An increase in the value of cottonseed has led to a resurgence of interest in improving the protein and oil quantity and quality of cottonseed. When improving seed quality, a breeder will always consider that lint quality and quantity cannot be sacrificed. Until a substantial market for improved cottonseed develops, lint yield and quality will continue to have the greatest economic impact. The value of cottonseed can be improved by increasing oil and protein content and by modifying fatty acid and amino acid profiles to satisfy animal and human nutrition needs. In addition, the potential of using cottonseed oil as a biofuel, the possibility of tailoring cottonseed oil to other end uses, and the expanded industrial uses of the oils are influencing current research directions at all levels.

2.1 Physiology

Several research programs have studied the impact of agronomic inputs on oil and protein components of seed quality. Egyptian researchers have found that the addition of fertilizers, including potassium, zinc, and phosphorus increased oil and protein yields (Sawan et al. 2007). In addition, a high nitrogen rate was found to decrease seed oil content while increasing seed protein content (Sawan et al. 2001).

The environment has a large influence on seed quality in general. The bulk of storage reserves of the cottonseed are produced during later stages of seed development (Benedict et al. 1976). In areas of temperate climate, low temperatures at the later stages of seed development have a marked influence on seed oil. As temperatures decrease, the rate of boll development decreases, as does the seed oil content. Relative amounts of individual fatty acids change in response to temperature, but the pattern of response in cottonseed is not clear (Kohel and Cherry 1983). This relationship is made even less clear by the differences in developmental age of bolls on a plant at any given time.

Specifically, there is a large environmental source of variation for seed oil content (Kohel 1978; Shaver and Dilday 1982). Early researchers noted the environment influenced oil content greater than protein content (Turner et al. 1976a). In particular, soils with increasing salinity in Uzbekistan were found to produce cotton with decreased oil content (Yuldasheva et al. 2004). The microenvironment of the cotton plant and the method of harvest also influence seed quality. Bolls located next to the main stem on branches in the center of the plant have the highest yield and quality, but seed quality declined the longer the bolls remained in the field (Kohel and Cherry 1983; Conkerton et al. 1993). As the harvest gets later, oil and protein contents of cottonseed tend to decrease.

The response of seed development and oil content to moisture varies. Chronic moisture stress has not been shown to produce any negative changes on seed oil content (Cherry et al. 1981b). An acute moisture stress at a late stage of boll development may adversely influence seed oil content because seed may be arrested in their development. Cotton plants stressed at early stages of boll development or under chronic stress generally compensate by boll shedding so that seed oil content is affected to a limited extent (Kohel and Benedict 1984).

Several classes (types) of cottons have been evaluated for oil and protein quality. Kohel (1978) surveyed over 1,300 accessions in the U.S. *G. hirsutum* L. germplasm collection for seed oil content. In a second publication, Kohel et al. (1985) surveyed the same accessions for protein content. The accessions came from two large groups of germplasm designated as “TX” and “SA.” These surveys identified the “TX” germplasm having consistently more oil and less protein than the “SA” group. These tetraploid members of the U.S. collection were evaluated for their compositional quality (Kohel 1978; Kohel et al. 1985), and as one would expect, there was wide variation in the germplasm for seed composition. The greater variability was found in the unimproved cottons. However, these cottons varied for other seed properties such as seed size and hull thickness, which had a large impact on compositional content.

Shaver and Dilday (1982) evaluated seed quality in Mexico for a select group of “TX” germplasm. They identified some accessions with higher oil and protein than commercial checks, thus having the potential to increase these seed quality factors in a breeding program. Variability within *G. arboreum*, several wild species, and cotton hybrids were measured by Indian research programs. The *G. arboreum* germplasm had the largest seed oil percent, with a range from 18 to 25% (Agarwal et al. 2003). Among the wild species, *G. lobatum* had 22.9% seed oil followed by *G. harknessii* with 22.2% (Gotmare et al. 2004). *Gossypium stocksii* had the lowest seed oil percent (10.3%). Cotton varieties are commonly grown commercially as essentially pure lines that have been selfed to achieve a certain degree of uniformity. India pioneered the cultivation of hybrid cotton for commercial use. These hybrid cottons range in oil content from 17.9 to 23.1% and range in protein content from 36.0 to 44.3% (Rajput et al. 2007).

2.2 Genetics/Breeding

Cotton breeders have made efforts to understand the relationships of seed quality parameters with lint yield and lint quality in various genetic materials. When comparing to lint yield parameters, these relationships often varied from one study to another. In one study, increased oil and protein were negatively correlated with increased lint yield (Mert et al. 2005). In a separate study, Wu et al. (2009) found protein to be positively correlated with lint yield. Yet another study established that oil and protein had no significant correlations with yield (Turner et al. 1976b). Seed index was highly correlated with both the seed protein and seed oil indices (Wu et al. 2009). For fiber quality, conflicting relationships were also found. Oil was positively correlated with strength and negatively correlated with fiber length (Mert et al. 2005). Protein percent was significantly negatively correlated with oil percent (Turner et al. 1976b; Song and Zhang 2007).

Both Azhar and Ahmad (2000) and Khan et al. (2007) estimated narrow sense heritability for seed oil percent as moderate in the F_1 and high in the F_2. Heritability estimates for seed oil ranged from 35 to 53% in the F_2 primarily due to additive effects (Kohel 1980; Ramos and Kohel 1987; Wu et al. 2010). Therefore, selection for improved oil content could be both quick and effective using a recurrent selection program.

In contrast, separate genetic analyses have shown that protein and oil content were primarily under nonadditive (dominance) gene effects (Singh et al. 1985; Dani and Kohel 1989; Ashokkumar and Ravikesavan 2008). Though studies disagree over whether additive or dominance effects primarily control seed and protein content; overall, favorable genetic effects provide evidence that these seed traits can be genetically improved.

The oil-bearing tissue of the cottonseed is the embryo; therefore, the embryo derives its genotype from both parents. However, the maternal parent provides the nourishment for the growing seeds. The findings of research projects disagree whether cytoplasmic or maternal effects are more significant in determining seed oil content. Wu et al. (2010) have found that cytoplasmic effects are important in the inheritance of seed oil content. In a comparison of glanded and glandless cottons, Ramos and Kohel (1987) found that glandless genotypes, on average, have a higher seed oil percent, and maternal effects were not significant among these genotypes. Other studies identify the maternal plant rather than cytoplasmic effects as a greater influence when improving oil and protein indices (Dani and Kohel 1989; Ye et al. 2003).

3 Molecular Biology/Biotechnology

With the increased identification and use of molecular markers in cotton, studies have been designed to identify regions of the cotton genome (quantitative trait loci, QTL) that determine the oil content of cottonseeds. In the first report of seed quality QTL, Song and Zhang (2007) identified genomic regions on chromosome D8 as responsible for oil percent and on chromosome D9 as responsible for protein percent. Subsequent research using different genetic material associated chromosome 4 and the short arm of chromosome 9 with oil percent (An et al. 2010; Wu et al. 2009) and chromosomes 2, 9, and 12 with protein percent (An et al. 2010).

Biotechnology approaches may be applied to improve food security by making more food available. In addition, this technology may be used to enhance nutritional composition or health value of foods in both the developed and developing world. Cotton is well positioned for the application of biotechnology to nutrition. Whole, fuzzy cottonseeds are composed of 20% crude fat and 23% crude protein. Cottonseed is primarily used as an animal feed, but cottonseed oil is desirable as a vegetable oil for human consumption because it is trans-fat free oil. Worldwide, most cottonseed oil is produced (Table 9.1) and consumed (Table 9.2) in China. The oil contains a 2:1 ratio of polyunsaturated to saturated fatty acids. The fatty acid profile of cottonseed oil is compared with other common vegetable oils in Table 9.3.

To further enhance the health value of cottonseed oil, researchers aim to alter the fatty acid profile by increasing stearic and oleic acids while reducing the palmitic acid content. There are scattered reports of breeding attempts to improve the compositional quality of cottonseed. These reports are characteristically positive, but do not appear to represent any continuous effort to breed for improved seed quality (Cherry et al. 1981b). Lukonge et al. (2007) have evaluated the fatty acid profile

Table 9.1 World production of cottonseed oil

	Production (thousand metric tons)		
	2008/2009	2009/2010	2010/2011
China	1,600	1,466	1,493
India	1,030	1,045	1,089
Turkey	116	100	109
United States	301	277	306
EU-27[a]	47	50	52
Other	1,751	1,737	1,832
World total	4,845	4,675	4,881

Source: USDA-FAS (2010)
[a]EU-27: Economic and political group of 27 states that comprise the European Union

Table 9.2 World domestic consumption of cottonseed oil

	Consumption (thousand metric tons)		
Country	2008/2009	2009/2010	2010/2011
China	1,595	1,463	1,490
India	1,038	1,049	1,085
United States	225	234	250
Turkey	140	103	113
EU-27[a]	47	54	54
Other	1,768	1,746	1,838
World total	4,813	4,649	4,830

Source: USDA-FAS (2010)
[a]EU-27: Economic and political group of 27 states that comprise the European Union

Table 9.3 Range of typical fatty acid composition (%) of various vegetable oils

Fatty acid	Cottonseed	Olive	Palm	Peanut	Rapeseed (canola)	Soybean	Sunflower
Myristic (C14:0)	0.5–2.0	0.1–1.2	0.5–5.9	<0.2		<0.5	<1.0
Palmitic (C16:0)	17–29	7–16	32–47	6–15.5	3–6	7–12	2–10
Stearic (C18:0)	1–4	1–3	2–8	1.3–6.5	1–4	2.0–5.5	1–10
Palmitoleic (C16:1)	<1.5			<1.0		<0.5	<1.0
Oleic (C18:1)	13–44	65–85	34–44	36–72	55–75	19–30	14–65
Linoleic (C18:2)	40–63	4–15	7–12	13–45	15–25	48–58	20–75
Linolenic (C18:3)	0.1–2.1	<1.5		<2.0	8–22	5–9	<1.5

Source: http://www.connectworld.net/whc/images/chart.pdf

in seed of cotton accessions and have shown that stearic and palmitic acids were positively correlated. These data suggest that it would be difficult to increase stearic acid while decreasing palmitic acid using selection. Where a plant breeding approach may be difficult, molecular approaches have been taken to modify the biosynthetic pathways of these fatty acids.

Several groups have successfully engineered high-oleic acid transgenic cottonseed lines through suppression of key enzymes in the fatty acid biosynthetic pathway (Chapman et al. 2001; Liu et al. 2002a, b; Sunilkumar et al. 2005). Liu et al. (2002a, b) were able to increase oleic acid from 15 to 77% and, in a separate transgenic line, increase stearic acid from 2 to 40%. However, the lines with increased stearic acid had poor germination and reduced survival.

4 Processing Cottonseed

For every pound of fiber, the cotton plant produces approximately 1.6 lb of cottonseed. This seed is fed to cattle, used as raw material in the cottonseed processing industry, and a small amount is exported. Throughout its history, cotton has been grown primarily for its fiber. With the development of the crushing industry and the more recent interest in cottonseed for biodiesel and for human food, however, the use of cottonseed on a commercial scale is gaining interest. Until the crushing industry developed, cottonseed generally had no cash value. Small quantities of seed were used for planting the next year's crop, for fertilizer, and for livestock feed. As cotton oil mills began to operate, the value of cottonseed increased.

The components of cottonseed are separated at an oil mill in a process called crushing. In the first step of crushing, ginned seeds are cleaned using screens to remove any leaves, twigs, or other trash. After cleaning, the short fibers still attached to the seed (linters) are removed with delinting machines. The delinting machines are similar to cotton gins and use circular saws to cut off the short fibers. After the linters are removed, the protective hull, which surrounds the cottonseed kernel, is cut and loosened. The hulls are separated from the kernels. After separation, the hulls are ready for marketing as animal feed. The kernels, or meats, are further processed and oil is extracted.

According to the National Cottonseed Products Association, in the last 50 years, major changes have been made in methods of removing oil from cottonseed. Extracting the oil was initially performed using a labor-intensive hydraulic press. Today, oil is removed from the seed primarily by mechanical screw presses, by solvent extraction, or both. For both processes, meats (kernels) pass through a series of heavy rollers that form the meats into thin flakes. In screw pressing, the flakes are first "cooked" to reduce moisture. They then move into the screw press. The screw press operates similar to a meat grinder. Oil is forced from the meats and flows through small openings in the barrel of the press to a chamber below. From there it is filtered and put in storage tanks. The extracted flakes come out of the other end of the press. After cooling, the flakes are ground into meal. The newest technology uses an expander which helps release the oil and prepares the kernels for oil extraction. The expanded kernels are exposed to an organic solvent that dissolves out the oil. The solvent is recovered and can be reused. Extracted kernels are also ground into meal.

Crude cottonseed oil from the mill requires further processing before it is used in food. The oil is refined, bleached, winterized, and deodorized before it can be used as food oil. During refining, sodium hydroxide is added and combines with the soapstock or "foots" portion of the crude oil. A centrifuge separates the soapstock and heavier impurities from the oil. During bleaching, a special type of clay is added that combines with the compounds that give the oil its yellow color. This clay is then filtered from the oil. Winterizing separates the components of oil that tend to turn cloudy and become solid at lower temperatures. Finally, deodorizing removes unwanted flavors and is the final purifying step in processing before its use as food oil.

5 Utilization of Cottonseed

Whole cottonseed is a source of protein (20%), energy (87%), and fiber (22%) for livestock (Ely and Guthrie 2008). Animal nutritionists recognize ginned whole cottonseed as a premium supplement for cattle and other ruminant animals (Blasi and Drouillard 2002). Cottonseed oil and meal are the two most valuable products of cottonseed. Oil makes up 16% of the products resulting from crushing cottonseed in an oil mill. Cottonseeds contain a significant amount of tocopherols, forms of Vitamin E, which contribute to the long shelf life of cottonseed oil (Smith and Creelman 2001). In addition to stability, cottonseed oil has no cholesterol, is high in polyunsaturated fatty acids, moderate in monounsaturated fatty acids, and low in saturated fatty acids (Table 9.3). This profile is considered heart healthy by many medical professionals. Most of the cottonseed oil used in the USA is consumed as salad or cooking oil. The remaining oil is used in shortening and in margarine.

Cottonseed meal is the second most valuable product of cottonseed. It may be sold in the form of meal, cake, flakes, or pellets. Cottonseed meal is used principally as feed for livestock and its major value is as a concentrated protein supplement. Fish farms are an emerging market for cottonseed meal. Fish farmers use cottonseed meal as an economical, highly nutritious alternative to fish meal. Fish meal is composed primarily of wild-caught fish, and the price of fish meal continues to climb as natural fish stocks decline.

5.1 Gossypol

Cotton is characterized by the presence of glands in the aerial vegetation and in the seeds. The glands form in the space left following lysis of cells. These lysigenous glands contain gossypol, which is an antinutritional compound, and dark pigments. Chemically gossypol is a sesquiterpene, a class of hydrocarbons which acts as a natural defense mechanism. In the aerial vegetation, gossypol and its precursors are present in the glands. In the seeds, gossypol and its isomeric forms are present in highly compartmentalized glands. Gossypol is sequestered in the glands and does not accumulate in other tissues.

Glanded cottonseeds can be fed to ruminant animals where microbial action in the rumen breaks down gossypol. There is some limitation in the amount of cottonseed, as a source of protein, which can be fed to lactating cows because high concentrations of glanded cottonseed in the feed can lead to the presence of gossypol in the milk. In monogastric animals, the gossypol in glanded cottonseed binds with protein causing protein deficiency and toxic effects. Because of this action of gossypol, it has been used as a male contraceptive (Wen 1980; Tsui et al. 1983). It is apparent that the removal of gossypol glands/gossypol from cottonseed would be beneficial (Hess 1976; Anonymous 1977; Rathbone 1977; Kohel and Yu 2007). In cottonseed crushing, oil is extracted and the meal is heat treated to bind gossypol. In the crushing process, some gland components are extracted with the oil that requires further refinements. These contaminants also limit oil storage so that periodic bleaching is required under long periods of storage. The heat treatment to bind gossypol binds it primarily with lysine. This lowers the quality of the amino acids in the meal. Supplemental lysine must be added in feed rations to compensate for the lysine lost during crushing.

If glands/gossypol were not present in the seeds, simpler and less energy-intensive processing could be utilized for oil extraction (Rathbone 1977). Such simpler processing would produce better quality oils and meal, and the meal would have a wider use potential. It could be a feed for both ruminant and monogastric animals as a higher quality protein source with greater economic value. A gland-free/gossypol-free cottonseed could be a human food source. Cotton is a global crop, and many areas of production are areas where human diets are deficient in proteins. The uses of glandless cottonseed as a food protein have been summarized by Lusas and Jividen (1987). The cottonseed kernel is the most common cottonseed product used commercially in food products. Flours, concentrates, and isolates from glandless cottonseed also have potential food uses due to diverse functionality and a protein content comparable with soy.

During the 1970s and 1980s there was a renewed interest in cottonseed, with emphasis on gossypol-free products for human food (Hess 1976; Anonymous 1977; Rathbone 1977). Several methods were developed to remove gossypol from cottonseed. They included chemical, mechanical, and genetic. Chemical methods were developed and used experimentally for gossypol removal (Cherry and Gray 1981). The most advanced mechanical separation method was the liquid cyclone process (Vix et al. 1971; Gardner et al. 1976). A pilot plant was built and successfully operated by the Plains Cottonseed Cooperative. However, the plant was not built for food-grade production, and unrelated financial problems halted further development and the project was terminated.

McMichael (1960) discovered two recessive genes ($gl_2gl_2gl_3gl_3$) that produced gland-free cotton plants. The genes originated in semiwild, nonadapted cottons. There was considerable linkage drag when trying to develop adapted cultivars. However, several commercial companies and public breeders developed improved agronomic cultivars. The most notable of these was Rogers Delinted Cottonseed Company.

This company not only bred glandless cottons, but they obtained FDA approval for a human food product. The approval was for a dehulled, roasted, whole kernel product sold under the name of "Cot-N-Nuts®." They marketed to the confectionary trade, and the main user was an energy bar product. Unfortunately, this product was labeled as hypoallergenic. Cottonseed, as other oilseeds, contains the same fraction of proteins that can cause allergenic reactions (Coulson et al. 1941, 1943). When consumers of the energy bar developed allergenic reactions, and lawsuits followed, Rogers Delinted Cottonseed Company went out of business.

Furthermore, the absence of gossypol glands in aerial vegetation of the cotton plant made the plants more attractive to other pests. Chewing insects fed vigorously on glandless plants, rabbits fed on young plants, and rodents would eat the seeds (Hinze et al. 2011). The degree to which these were major problems to prevent the successful production of glandless cultivars was never fully evaluated. These problems were risks that were a disincentive to the adoption of glandless cultivars. Breeding programs, other than Rogers Delinted Cottonseed Company, had not made a major commitment to glandless cultivars, and the two recessive glandless genes, with linkage drag, were a further hurdle to overcome. The later report of a single semidominant gene ($Gl_2^e Gl_2^e$), which produced glandless cotton plants and seeds, failed to invigorate additional interest (Kohel and Lee 1984). The perceived production problems, and no clearly identified product potential, left glandless cotton breeding in a state of limbo.

The obvious advantages of a glandless/gossypol-free cottonseed continue to spur research efforts. Researchers have tried without success to introduce the glanded plant/glandless seed trait from *G. sturtianum* (Dilday 1986; Altman et al. 1987; Mergeai et al. 1997; Vroh et al. 1999). The use of biotechnology tools offers hope of producing a glanded plant with glandless seeds. Such a plant would avoid the understandable reservations of growing a plant that is glandless.

Different biotechnological approaches to produce gossypol-free cottonseed have been proposed: from the stopping of gossypol synthesis, to the degradation of gossypol, and to the prevention of gland formation (Koshinsky et al. 1994; Chen et al. 1995, 1996; Yu et al. 2000a, b; Decanini et al. 2001; Kohel et al. 2001; Martin et al. 2003). The theory of the approaches is rather straightforward; however, the implementation has proven to be difficult and complex. To date there has been successful interruption of gossypol synthesis to the extent that gossypol has been reduced, but not eliminated (Sunilkumar et al. 2006).

Cotton is the second most important oilseed. However, since the fiber is cotton's primary and most valuable product, the major thrust of breeding programs is devoted to fiber. The seed cannot be ignored, however, and the production of gossypol-free seed would enhance the overall value of cotton production. Cottonseed oil is an established industry that would not have to change, but it could be enhanced with better quality and lower costs with gossypol-free seeds. However, the main change with the production of gossypol-free seed would be the protein component of the seed. Not only would the quality be enhanced by no longer binding lysine, but also wider uses could be found as livestock feed, pet foods, and human food.

5.2 Chemical Composition

Numerous studies have reported on the variability of cottonseed constituents and chemical composition (Stansbury et al. 1956; Pandey and Thejappa 1975; Sood et al. 1976; Cherry et al. 1978, 1981a; Kohel 1980, 1998; Cherry and Leffler 1984; Kohel and Cherry 1983; Kohel et al. 1985). Currently, the National Cotton Variety Tests report on the percentage of oil, protein, and gossypol in the cottonseed samples. Values are usually reported as a percentage of the whole seed, flour, protein fraction, or oil fraction. The use of percentages is useful in merchandizing ginned whole cottonseed, but they are more difficult to interpret when trying to determine specific sources of variation and specific effects because percentage values are interdependent. In general, the experimental results reported variability associated with years, locations, and cultivars. Cultivars generally show the largest source of variability. The average cottonseed constituents for the national standards in the National Cotton Variety Testing Program (2007) were seed index = 9.4 g/100 seed, oil = 20.04%, protein = 23.38% (nitrogen% × 6.25), and gossypol = 1.27%. These values are based on fuzzy cottonseed. Acid-delinted seeds have higher percentage of the constituents because the variable amount of fuzz is removed, but the oil- and protein-bearing tissue, the kernel/embryo, is the tissue of interest. The seed coat represents about 38% of the acid-delinted seed so that there is about 40% oil in the kernel/embryo (Kohel 1978). The oil is made up of primarily three fatty acids, palmitic (C16:0) = 24.18%, oleic (C18:1) = 17.51%, and linoleic (C18:2) = 54.23%. The key remaining fatty acids are myristic (C14:0) = 0.89%, palmitoleic (C16:1) = 0.71%, and stearic (C18:0) = 2.60%.

Cottonseed flour has a high quality amino acid profile (Table 9.4). Glandless/gossypol-free flour would not be reduced in quality by the heat binding of gossypol to amino acids (in particular, lysine). Gland-free/gossypol-free flour could be used as a protein source in combination with other ingredients to produce various products. The original "Incaparina" formulation (protein-rich dietary supplements based on cottonseed flour, or soya and vegetables, Bender 2005) included 38% glanded cottonseed flour (Call and Levinson 1973; Popkin and Latham 1973; Orr 1977). Such nutritional products would be enhanced with the availability of gossypol-free flour. Experimentally, various products were produced to evaluate the degree to which cottonseed flour could be added to produce an acceptable product (Cherry et al. 1981a; Cherry 1983, 1985). A project was reported to use glandless cottons to improve the nutrition of the Ivory Coast diets (Bourely 1988). Another extensive project was in Egypt in which glandless cottonseed enhanced cookies were produced to provide a protein supplement for school children. Despite the success of this activity, widespread glandless cottons were not adapted to sustain this effort (Anonymous 1980).

Although gossypol-free flour has a wide range of uses, protein extracts should provide higher value uses in human food products. Protein extracts can be isolated from storage proteins, nonstorage proteins, or the total protein fraction (Lawhon et al. 1977; Lusas et al. 1977; Cherry and Berardi 1982; Rhee 1988). Proteins of

Table 9.4 Composite amino acid profile of fat-free cottonseed flour

Amino acid	(g/100 g sample)
Alanine	2.13
Valine	2.17
Glycine	2.21
Isoleucine	1.56
Leucine	3.24
Proline	1.97
Threonine	1.73
Serine	2.38
Methionine	0.76
Phenylalanine	2.82
Aspartic acid	4.92
Glutamic acid	10.42
Tyrosine	1.50
Lysine	2.46
Histidine	1.39
Arginine	5.42
Half cystine	0.67
Total	47.74

Source: Cherry et al. (1978, 1981b) and Salunkhe et al. (1992)

cottonseed are highly digestible in humans. The relative human digestibility of proteins from several sources is cottonseed flour (90%), soy flour (86%), milk and cheese (95%), peanuts (94%), and rice flour (88%) (Anonymous 2007). The amino acids in cottonseed flour make up about 50% of the defatted flour. The amino acid profile is variously expressed as a percentage of the flour or percentage of the protein fraction (Table 9.4).

6 Future of Cottonseed

Cottonseed is currently consumed as oil, meal, and a whole seed animal feed. From this review of the research on cottonseed quality, it is apparent that the presence of the antinutritional constituent, gossypol, is a limiting factor in its utilization. The technology and genetic resources are available to remove glands/gossypol from cottonseed and its products. The limitations to do this are the funding for their implementation and the economic drivers for markets for this new cottonseed and its products. A gossypol-free cottonseed would compete as new products in already existing markets.

Products from gossypol-free cottonseed could be used as feed for monogastric livestock and in the higher valued pet and human food product industries. However, as a human food, only dehulled, roasted, whole-kernel, glandless cottonseeds have FDA approval. Therefore, regulatory approval would have to be obtained for additional human food items.

From the production side, the growing of glanded and gossypol-free cotton cultivars would have to be segregated to prevent contamination. This segregation would have to continue through the ginning and processing of the cottonseed. The human food maximum allowable limit of gossypol is 450 ppm, which would require vigorous control of the gossypol-free cottonseed production. Mechanical or chemical removal of glands/gossypol would not require such controls of the growing or ginning of cottonseed. However, they require changes and large initial investments in these technologies. The long-term advantage is in genetic development of glandless/gossypol-free cottonseed cultivars. Such was the prediction in 1954 (Eckey 1954).

Cottonseed oil is considered to be premium cooking oil in that it is trans-fat free. According to the National Cottonseed Products Association, since New York City announced it would ban trans-fats from restaurants, the demand for cottonseed oil has doubled. The demand is expected to continue with bans in Philadelphia, statewide in California, and more bans likely to come. In addition, cottonseed oil can be certified Kosher. Many legumes are not considered Kosher, so cotton's primary competitors, including peanut, soybean, and even corn oil due to formulations blending corn with legumes, cannot compete in this marketing opportunity.

New opportunities for food use are now also possible because of recent biotechnological advances in producing seed with reduced gossypol (Sunilkumar et al. 2006; Townsend and Llewellyn 2007). The process currently used to remove gossypol from cottonseed damages protein value (Freidman 1996). If seed can be produced completely gossypol free, then the protein value of cottonseed should also inevitably improve.

Historically, the largest market for cottonseed has been the dairy industry. That has recently changed as the best market for cottonseed is now the food processing industry due to their demand for cottonseed oil. Those seeds that were once sold only to offset ginning costs are now being viewed as an increasingly important source of income. It's not just about the fiber value per acre anymore. The industry is viewing cottonseed as a viable source of revenue, thereby adding value to each and every acre of cotton.

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