Chapter 37

FOOD AND FEEDING QUALITY OF COTTONSEED

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INTRODUCTION

The research objective for production of quality cottonseed that has been a major concern of cottonseed researchers for many years is to:

> "Identify the genetic variability of cottonseed composition, determine the genetic control of cottonseed traits, and develop preferred cottonseed quality germplasm; develop an understanding of developmental processes of the plant that leads to improved cottonseed composition, and develop methods to measure and evaluate quality parameters; and identify cultural practices, production systems, and handling procedures suited for the production of high quality seeds" (National Cotton Research Task Force, 1979).

During the past 80 years, intermittent periods of increased research on cottonseed composition have improved understanding of the influence genetics and growing location have on seed quality, and the quantity of such seed storage constituents as oil, protein and gossypol. These periods of increased interest, however, have been short lived, and little progress has been made toward the stated objective.

PAST RESEARCH EFFORTS ON SEED QUALITY (1900-1970)

Most early studies on the effects of genetics and growing location on cottonseed quality were analyses of commercial samples from a limited geographical area.

They showed that both factors should be of concern in research on cottonseed composition (Garner *et al.*, 1914; Barrow-Agee, 1918; Law, 1919; Harrington, 1928; Ware, 1931; Sievers and Lowman, 1932; Hancock, 1942).

During the crop years of 1935 to 1937, Pope and Ware (1945) analyzed delinted cottonseed from 16 varieties of cotton grown at 12 to 15 locations in the United States Cotton Belt. This study was the first designed to test the relative effect of variety, location season, and the statistical interactions of these main effects on the oil and protein content of cottonseed. It showed that location averages of oil and protein data varied widely among years, indicating that levels of these constituents in cottonseed are affected by weather conditions (rainfall, temperature) (Table 1). The effect of variety on oil and protein composition was

Table 1. Mean percentages of oil and protein in moisture-free, delinted cottonseed.[1] Data are averages of all varieties within the 12 to 15 locations during the three year period of 1935 to 1937. (Summarized from Pope and Ware, 1945.)

	Component composition (percentage)					
	1935		1936		1937	
Location	Oil	Protein	Oil	Protein	Oil	Protein
Prattville, Ala.	—	—	19.7	24.2	20.4	24.7
Marianna, Ark.						
Delta	23.7	22.0	24.4	21.7	26.2	20.8
Upland	22.1	24.5	20.3	24.0	23.4	23.5
Experiment, Ga.	—	—	24.2	20.5	21.0	24.0
Baton Rouge, La.	23.5	20.9	23.3	25.6	26.7	21.7
Stoneville, Miss.	23.2	22.2	23.0	24.4	24.7	23.9
Statesville, N.C.	24.2	20.7	25.4	21.1	25.1	22.9
Stillwater, Okla.	21.2	24.7	17.6	24.8	19.0	26.8
Florence, S.C.	21.0	23.0	24.6	22.4	23.0	22.3
Jackson, Tenn.	20.9	22.8	21.3	24.4	21.4	23.5
Knoxville, Tenn.	21.8	22.6	22.4	22.4	21.9	24.2
College Sta. Tex.	22.1	23.3	20.7	22.6	16.1	24.8
Greenville, Tex.	21.4	24.0	19.7	23.8	17.8	25.3
Lubbock, Tex.	21.6	24.4	22.4	24.8	23.2	23.7
Brazos Valley, Tex.	—	—	—	—	19.0	24.5
Average (all locations)	22.2	22.9	22.1	23.3	21.9	23.8

[1]See Table 2 for list of varieties.

also shown to be significant (Table 2), as was season. For all three variables, the effects of varieties were much greater than the interactions of varieties by locations or seasons, indicating that chemical composition is basically a varietal characteristic. Thus, cottonseed oil and protein contents are dependent on variety. A consideration of the variables associated with this term in the breeding program should result in the isolation of genetic lines that are superior in either one or both of these constituents.

Further statistical comparison of the oil and protein data showed that they are independent of each other as far as their genetics is concerned but are negatively correlated when the effects of environment are included in the analysis of the data (Pope and Ware, 1945). Previously, Ware (1931) had pointed out negative correlation for cottonseed oil and protein among samples gathered from widely different environments.

Stansbury *et al.* (1954) demonstrated that the oil content of moisture-free

Table 2. Mean percentages of oil and protein in moisture-free, delinted cottonseed.[1] Data are averages of the 12 to 15 locations for each year. (Summarized from Pope and Ware, 1945.)

	Component composition (percentage)					
	1935		1936		1937	
Variety	Oil	Protein	Oil	Protein	Oil	Protein
'Acala (Roger)'	22.2	22.8	21.8	23.1	21.8	23.4
'Arkansas 17'	22.6	22.2	22.4	22.7	22.4	23.1
'Cleveland (W)'	21.4	22.8	20.6	23.4	20.8	23.8
'Cook 912'	23.1	22.3	22.6	23.0	22.8	23.2
'Delfos 4'	22.9	23.0	23.0	23.2	22.5	23.4
'Deltapine'	22.3	23.4	22.0	23.8	21.7	24.2
'Dixie Triumph 759'	23.1	21.8	23.1	22.4	23.0	22.8
'Farm Relief'	21.1	23.8	21.2	23.7	21.2	24.5
'Half and Half'	22.6	24.6	22.6	25.0	22.3	25.6
'Mexican Big Boll'	22.2	23.3	22.5	23.7	22.2	24.1
'Qualla'	20.0	23.0	20.0	23.0	19.7	23.5
'Rowden 2088'	22.7	22.9	22.6	23.4	22.5	24.2
'Startex 619'	22.5	23.0	22.4	23.6	22.4	23.8
'Stoneville 5'	21.8	22.3	21.8	22.7	21.1	23.3
'Triumph 44'	23.4	22.8	23.4	23.6	22.9	24.2
'Wilds 5'	21.9	22.9	21.7	22.9	21.7	23.3
Average (all varieties)	22.2	22.9	22.1	23.3	21.9	23.8

[1]See Table 1 for list of locations.

Table 3. Mean percentages of oil in moisture-free cottonseed kernels. Data are from varieties grown at 13 locations, 1947-1949.[1] (Summarized from Stansbury *et al.*, 1954.)

	Oil composition (percentage)			
Location	1947	1948	1949	Average
Statesville, N.C.	34.4	29.9	38.0	34.1
Florence, S.C.	41.5	38.5	37.9	39.3
Tifton, Ga.	33.1	37.3	38.6	36.3
Auburn, Ala.	37.4	37.6	37.6	37.5
Jackson, Tenn.	34.8	32.5	39.8	35.7
Stoneville, Miss.	35.1	37.1	36.4	36.2
St. Joseph, La.	39.9	38.2	42.0	40.0
Chickasha, Okla.	33.8	33.5	38.4	35.2
Greenville, Tex.	33.9	33.2	36.9	34.7
College Sta., Tex.	38.3	33.2	34.8	35.4
State College, N.M.	37.2	36.2	37.7	37.0
Sacaton, Ariz.	35.2	35.1	37.4	35.9
Shafter, Calif.	37.0	30.2	38.2	35.1

[1]Varieties listed in Table 4.

Table 4. Mean percentages of oil in moisture-free cottonseed kernels. Data are from varieties grown at 13 locations 1947-1949.[1] (Summarized from Stansbury *et al.*, 1954.)

	Oil composition (percentage)		
Variety	Low	High	Average
'Acala 4-42'	27.6	41.2	35.4
'Acala 1517W'	32.4	42.7	37.7
'Rayden 41B'	29.4	43.1	36.5
'Mebane Watson's'	28.8	41.0	35.8
'Stoneville 2B'	28.4	43.4	37.8
'Deltapine 15'	26.8	42.4	35.6
'Coker 100W'	28.3	43.3	36.5
'Coker Wilds'	29.6	42.6	35.9
Average	26.8	43.4	36.4

[1]Locations listed in Table 3.

cottonseed kernels from seeds of eight commercial cotton varieties grown at 13 locations from 1947 to 1949 ranged from 26.8 to 43.4 percent (Tables 3 and 4). Analysis of variance of these data showed that both variety and growing location

Table 5. Average oil, nitrogen and gossypol contents of moisture-free cottonseed kernels from selected varieties grown at 13 locations during three years, 1947-1949.[1] (Summarized from Stansbury *et al.*, 1956.)

Component	Variety				
	'Acala 4-42'	'Acala 1517W'	'Stoneville 2B'	'Deltapine 15'	'Coker 100W'
Percent of moisture-free kernels:					
Oil	35.4	37.7	37.4	35.6	36.5
Nitrogen (Protein)[2]	6.5(40.6)	6.3(39.4)	6.0(37.5)	6.4(40.0)	6.3(39.7)
Gossypol	0.8	1.1	1.2	1.2	1.2
Gm/100 moisture-free kernels:					
Weight	6.6	7.3	6.5	5.5	5.8
Oil	2.3	2.7	2.4	2.0	2.1
Nitrogen (Protein)[2]	0.4(2.5)	0.5(3.1)	0.4(2.5)	0.3(1.9)	0.4(2.5)
Gossypol	0.06	0.08	0.08	0.07	0.07

[1]Varieties and locations listed in Tables 3 and 4.
[2]Protein determined as N x 6.25.

have significant influence on the oil content of cottonseed kernels. Correlations on the basis of years at locations between kernel oil content, temperature and rainfall showed that these weather conditions significantly influenced oil quantities.

Stansbury *et al.* (1956) also analyzed the relationship between the oil, nitrogen and gossypol content of moisture-free cottonseed kernels from the samples used in the oil study summarized above (Table 5). Both variety and growing location had a highly significant influence on each constituent whether expressed as percentage of the kernel or as weight of constituent per 100 kernels. Each cultivar showed a significant positive correlation between oil and gossypol and significant negative correlations between oil and nitrogen, and gossypol and nitrogen, on the basis of percentage of constituent in the kernels. Amounts of both oil and nitrogen improved with increased kernel size.

In other studies with these same varieties, locations and crop years, Stansbury *et al.* (1953b) showed that the influence of variety and growing location factors on total, acid-soluble, phosphatide, inorganic and phytin phosphorus (calculated on a moisture-free or moisture-and-oil-free basis) was statistically significant. A significant positive correlation coefficient was obtained for the relationship between total phosphorus and phytin phosphorus contents of the moisture-free kernels. Analysis of variance showed that the influence of variety and of location and year combined to be highly significant for the iodine value of the cottonseed oil (Stansbury *et al.*, 1953a). The iodine value was negatively correlated with temperature.

Fatty acid composition of oils extracted from cottonseed of various cultivars grown at different locations during crop years 1961 and 1962 are summarized in Table 6 (Bailey *et al.*, 1966). The percentages of the major fatty acids varied significantly: palmitic, 21.4 to 27.4 percent; oleic, 13.9 to 19.5 percent; and linoleic, 48.8 to 57.2 percent. Deltapine 15 and Acala 44WR oil had the highest levels of saturated fatty acids. Acala 1517A and the two Stoneville varieties had the lowest oleic acid among all cultivars, while Stoneville 2B had one of the highest levels of this fatty acid. The malvalic acid (cyclopropene fatty acid) content in oil of the different cultivars ranged from 0.64 (Acala 44WR) to 0.98 percent (Stoneville 3203). Regression analyses showed that palmitic acid rather than stearic acid is associated with an increase in linoleic acid, indicating a connection between these fatty acids during their biosynthesis in cottonseed.

All of these earlier studies emphasized the role environment plays in cottonseed quality. A study by Barrow-Agee Laboratories (1918) showed moisture levels (rainfall) between May and July affected oil percentages of Alabama-grown cottonseed (the age of these seeds was not known). Stansbury *et al.* (1953a, 1953b, 1956) and Pons *et al.* (1953) found that the most critical period during which weather affected the percentage of oil and gossypol in maturing cottonseeds was when they had grown for 35 days beyond the flowering stage. Moisture and temperature were shown to be the most influential environmental factors.

Table 6. Fatty acid composition of oils from cottonseed of selected commercial varieties grown at different locations during crop years 1961 and 1962.[1] (Summarized from Bailey *et al.*, 1966.)

	Fatty acid content (percentage)						
Variety	Myristic	Palmitic	Palmitoleic	Stearic	Oleic	Linoleic	Malvalic
Lockett 88A	1.2	26.2	0.7	2.9	19.5	48.8	0.66
Deltapine 15	1.1	27.1	1.0	3.0	18.1	49.0	0.72
Acala 44WR	1.0	27.4	1.1	2.7	17.0	50.3	0.64
Paymaster 54B	0.8	23.9	0.7	3.2	17.2	53.4	0.76
Acala 4-42	1.1	24.8	1.1	3.3	16.2	52.8	0.73
Stoneville 62	0.9	23.7	0.8	2.9	17.1	53.9	0.74
Coker 100A	1.0	24.4	0.6	2.6	15.0	55.4	0.84
Paymaster 101A	0.9	21.8	0.5	3.0	18.2	54.9	0.82
Acala 1517A	1.1	23.4	0.6	2.5	16.6	55.1	0.68
Stoneville 3202	0.8	24.2	0.6	2.3	13.9	57.2	0.98
Stoneville 2B	0.8	21.4	0.9	2.9	17.9	55.2	0.76
Average	1.0	24.4	0.8	2.8	17.0	53.3	0.76

[1]Cottonseed grown at Chickasha, Okla.; Huntsville, S.C.; Plainview, Tex.; Scott, Miss.; Stoneville, Miss.; Tempe, Ariz.; University Park, N.M.; and Vernon, Tex.

Table 7. Mean percentages of constituents in cottonseed of 97 varieties from various genome groups of *Gossypium*. (Summarized from Pandey and Thejappa, 1975.)

Item	Genera				
	G. arboreum	*G. herbaceum*	*G. hirsutum*	*G. barbadense*	Mean
Number of samples	30	11	46	10	
Oil (10%-moisture basis):					
Lowest value	29.9	26.7	27.9	25.5	25.5
Highest value	35.3	35.3	37.9	34.4	37.9
Mean	32.2	31.3	33.3	28.8	32.3
Protein (moisture-free basis):					
Lowest value	28.5	30.8	30.3	32.0	28.5
Highest value	38.1	37.9	42.8	41.1	42.8
Mean	34.0	34.5	36.2	36.2	35.3
Free gossypol (moisture-free basis):					
Lowest value	0.57	0.82	0.59	1.22	0.57
Highest value	2.38	1.96	2.35	2.41	2.41
Mean	1.27	1.44	1.32	1.72	1.36

In experiments that evaluated the specific effects of environment on seed development (Gipson and Joham, 1968, 1969b; Gipson, 1970), investigators studied the effects of night temperatures on the growth of cotton plants that were adapted and not adapted to the Texas High Plains environment. Their data showed that during the growing season, as night temperature increased, so did boll development; the response was statistically linear. Seed nitrogen increased during this same period of development. On the other hand, oil composition responded in a curvilinear fashion, reaching an optimum level when the temperature was about 20C (see also Chapter 5).

SEED QUALITY RESEARCH IN THE EARLY 1970's

Pandey and Thejappa (1975) studied the interrelationship between oil, protein and free gossypol in cottonseed of 97 varieties of *Gossypium arboreum, G. herbaceum, G. hirsutum and G. barbadense* (Table 7). Protein and oil, and protein and free gossypol were negatively correlated. No significant correlation, either positive or negative, was noted between oil and free gossypol. The results of this study suggested that any increase in protein content in cottonseed will result in a relative reduction in oil and free gossypol, and vice versa. The observation of

Table 8. Mean values of three seed quality traits from 17 locations in 1973.[1] (Summarized from Turner *et al.*, 1976a.)

Location	Component content (percentage)		Seed index (g/100 seed)
	Oil	Protein	
Arvin, Calif.	19.1	22.4	10.19
Chowchilla, Calif.	18.7	21.4	10.01
Tulare, Calif.	18.9	21.7	9.74
Maranna, Ariz.	18.1	20.4	9.77
Phoenix, Ariz.	19.6	21.2	9.95
Safford, Ariz.	20.6	20.3	9.62
Las Cruces, N.M.	18.9	21.6	10.11
El Paso, Tex.	20.8	20.9	10.70
Altus, Okla.	19.1	21.3	10.50
Chickasha, Okla.	22.5	20.2	10.47
Clarksdale, Ark.	17.4	22.7	8.61
Rohwer, Ark.	19.3	21.3	9.89
Portageville, Mo.	19.6	21.5	10.54
Bossier City, La.	20.5	21.5	9.84
St. Joseph, La.	21.7	18.8	9.55
Jackson, Tenn.	18.4	22.9	9.65
Rocky Mount, N.C.	19.9	20.8	9.01

[1]Acid-delinted, moisture-free cottonseed.

no real correlation between oil and free gossypol means that any improvement in cottonseed oil content will not result in a similar increase in gossypol content, findings important to cotton breeders interested in increasing the oil content of cottonseeds.

Percentages of oil and protein and seed index were determined on cottonseed samples from Coker 310, Deltapine 16, Lockett 4789A and Acala 1517-70 of the 1973 National Cotton Variety Tests (Tables 8 and 9) (Turner *et al.*, 1976a). Samples of four cultivars from 17 locations were used to study the seed quality parameters. Statistically, growing location had a greater influence on percentage of oil in cottonseed than the cultivar. It was suggested that a differential response of cultivars across the 17 locations for oil content was a result of genotypic differences in growth and fruiting patterns and the cultivars' response to diverse climates. Cultivar had as much influence on protein content as growing location conditions, and the interaction term of cultivar x growing location was not significant, meaning that both variables influenced cottonseed protein content in a similar way.

A negative correlation was noted between the oil and protein content of cottonseed from all cultivars used in the 1973 National Cotton Variety Tests (Turner *et al.*, 1976b), but only in Coker 310 and Deltapine 16 was the negative correlation significant. These authors suggested that if cotton geneticists checked early-stage breeding lines for cottonseed oil and protein, they could discover genotypes with higher levels of both of these constituents than current cultivars.

Table 9. Mean values of seed quality factors of four cultivars from 17 locations in 1973.[1] (Summarized from Turner *et al.*, 1976a.)

	Component content (percentage)		Seed index
Cultivars	Oil	Protein	(g/100 seed)
Coker 310	19.5	21.8	9.2
Deltapine 16	19.5	20.8	9.3
Lockett 4789A	19.6	21.5	10.2
Acala 1517-70	19.8	20.8	10.8

[1]Acid-delinted, moisture-free cottonseed.

SEED QUALITY RESEARCH ON GLANDLESS COTTONSEED

McMichael (1959) caused considerable excitement in the cotton industry when he published data indicating that varieties with gossypol-free cottonseed could be developed simply by selecting for the proper alleles at two genetic loci. Seeds from plants that are homozygous recessive $gl_2\ gl_2\ gl_3\ gl_3$ (gl = glandless) are

essentially free of gossypol and related substances (McMichael, 1960; Lee, 1962; Wilson and Lee, 1971; Barrow and David, 1974). Reviews on the genetic development of glandless cottons were presented by Hess (1976, 1977a).

Lawhon *et al.* (1976) analyzed ginned cottonseeds and kernels of 16 new and experimental varieties (eight each of glanded and glandless) for oil, protein, total gossypol, fatty acids and amino acids (Tables 10, 11 and 12). Oil in glanded, ginned seed and kernels varied significantly among varieties, averaging 21.0 and 37.8 percent, respectively (Table 10). Those of glandless samples also varied widely, averaging 21.1 and 39.7 percent. There was little apparent difference in the mean values for oil in seed from the two types of cotton; the mean value of oil in glandless kernels was about 2 percent greater than that in the glanded kernels. The average weight of 100 glandless kernels was 0.5g heavier than that of the glanded kernels. Glanded, ginned cottonseed and kernels had slightly higher average percentages of protein than those of the glandless samples. A significant amount of variability was noted for seed and kernel weights and protein content among glanded and glandless varieties. Little difference was noted in the gossypol content of cottonseed kernels, which ranged from 1.1 to 1.3 percent for glanded and from 0.01 to 0.03 percent for glandless varieties. Gossypol content in the glandless cottonseed sample was probably due to contamination with glanded seeds.

Palmitic acid ranged from 17.6 to 24.8 percent and from 17.6 to 26.0 percent in cottonseed oil from glanded and glandless varieties, respectively (Table 11). Oleic acid ranged from 15.0 to 18.7 percent and from 16.0 to 19.2 percent, respectively, in oil from glanded and glandless varieties; linoleic acid ranged from 52.7 to 60.5 percent and from 52.1 to 60.4 percent in the corresponding oils. Similar ranges of cyclopropene fatty acids were noted in glanded (0.06 to 0.31 percent) and glandless (0.07 to 0.32 percent) cottonseed oils. Mean values for individual fatty acids did not vary appreciably between glanded and glandless cottonseed oils.

Protein from cottonseed of glanded and glandless varieties was found not to differ substantially in amino acid composition (Table 12). Variations among varieties within each type of cottonseed were found to be minimal and of the same general magnitude.

Progress is being made in developing glandless cottons that outyield glanded cottons in lint and seed (Cooper and Hyer, 1977; Ray and Supak, 1977; Phelps *et al.*, 1979). The protein and oil composition of some varieties of glandless seed is comparable or better than that of glanded varieties and is affected by genetic and agronomic factors (Cherry *et al.*, 1977; Cooper and Hyer, 1977; Phelps *et al.*, 1979).

Table 10. Analytical data[1] on cottonseed and kernels of 16 varieties.[2] (Summarized from Lawhon *et al.*, 1976.)

Analyses	Variety								Mean
	A	B	C	D	E	F	G	H	
Ginned cottonseed, glanded:									
Oil (percent)	23.2	20.0	21.2	17.4	21.7	21.8	21.4	21.6	21.0
Protein (percent)	21.2	23.6	23.2	22.2	23.2	25.9	24.0	21.6	23.1
Weight (g/100 seed)	10.8	11.3	8.7	9.1	10.7	10.1	10.3	9.1	10.1
Ginned cottonseed, glandless:									
Oil (percent)	21.0	20.0	17.6	20.7	23.9	23.4	25.6	16.5	21.1
Protein (percent)	23.0	24.0	23.0	24.0	23.3	23.1	20.0	19.6	22.5
Weight (g/100 seed)	11.6	10.9	7.6	12.6	13.0	11.9	10.4	7.0	10.6
Kernels, glanded:									
Oil (percent)	40.5	36.7	38.1	36.4	37.7	37.8	35.6	39.4	37.8
Protein (percent)	38.5	41.6	39.1	41.1	39.2	40.0	40.9	36.8	39.3
Total gossypol (percent)	1.3	1.3	1.3	1.1	1.3	1.2	1.3	1.2	1.2
Weight (g/100 kernels)	6.0	6.8	5.6	6.9	7.3	6.9	6.4	6.2	6.5
Kernels, glandless:									
Oil (percent)	39.5	38.3	38.3	36.6	40.6	39.7	43.9	40.3	39.7
Protein (percent)	41.0	41.4	40.0	40.9	39.9	39.2	31.6	37.3	38.9
Total gossypol (percent)	0.02	0.01	0.01	0.02	0.01	0.03	0.01	0.03	0.02
Weight (g/100 kernels)	6.6	6.7	6.5	9.0	8.3	7.5	5.5	6.0	7.0

[1]Dry weight basis.

[2]Cottonseed supplied by ACCO Seed, Plainview, Tex.; L. Bird, Texas A&M Univ.; Coker's Pedigreed Seed Co., Lubbock, Tex.; Dunn Seed Farms, Inc., Lamesa, Tex.; Gregg Seed Farms, Plainview, Tex.; Lambright Seed Farms, Slaton, Tex.; Lockett Seed Co., Vernon, Tex.; N.R. Malm, New Mexico State Univ.; and U.S. Cotton Research Station, Shafter, Calif.

Table 11. Composition of fatty acids (percentage) in cottonseed oils of 16 varieties.[1] (Summarized from Lawhon *et al.*, 1976.)

Fatty acids	Variety								Mean
	A	B	C	D	E	F	G	H	
Glanded cottonseed oil:									
Myristic	0.8	1.5	0.7	1.0	1.0	0.6	0.8	0.6	0.9
Palmitic	23.9	24.6	24.0	17.6	22.1	22.1	24.5	24.8	23.0
Stearic	2.1	2.2	2.1	2.2	2.0	2.2	2.4	2.5	2.2
Oleic	18.3	18.1	16.3	18.2	16.4	20.7	18.7	15.0	17.7
Linoleic	54.9	52.7	56.4	60.5	58.0	53.9	53.0	57.1	55.8
Cyclopropenes	0.28	0.28	0.10	0.31	0.31	0.06	0.23	0.29	0.23
Glandless cottonseed oil:									
Myristic	0.8	0.7	0.7	0.9	0.8	0.7	0.6	0.6	0.7
Palmitic	24.0	20.3	17.6	26.0	24.1	22.1	26.0	20.8	22.6
Stearic	2.1	2.0	2.1	2.4	2.0	1.9	2.4	2.1	2.1
Oleic	16.0	17.1	19.2	17.9	17.3	18.6	16.3	19.2	17.7
Linoleic	56.5	59.4	60.4	52.1	55.8	56.1	54.7	57.0	56.5
Cyclopropenes	0.28	0.32	0.24	0.11	0.07	0.27	0.23	0.28	0.23

[1]Sources of varieties noted on Table 10.

Table 12. Amino acid composition of cottonseed protein of 16 varieties.[1] (Summarized from Lawhon *et al.*, 1976.)

Amino acids	Glanded seed			Glandless seed		
(g/16g N)	High	Low	Mean	High	Low	Mean
Lysine	4.6	4.2	4.4	4.6	4.3	4.5
Histidine	2.8	2.6	2.7	2.9	2.6	2.7
Arginine	12.3	10.9	11.6	13.2	11.2	12.1
Tryptophan	1.4	1.0	1.2	1.3	1.0	1.2
Half-cystine	3.4	2.3	2.6	2.6	2.2	2.4
Aspartic acid	9.5	8.8	9.2	9.3	8.6	9.1
Threonine	3.2	2.8	3.0	3.2	2.8	3.0
Serine	4.4	3.9	4.2	4.4	3.9	4.2
Glutamic acid	22.4	20.5	21.7	22.4	19.9	21.6
Proline	4.0	3.1	3.6	3.7	3.1	3.4
Glycine	4.5	3.8	4.1	4.6	3.7	4.1
Alanine	4.2	3.6	3.9	4.2	3.6	3.9
Valine	4.7	4.3	4.5	4.8	4.1	4.4
Methionine	1.8	1.3	1.5	1.7	1.2	1.4
Isoleucine	3.4	3.0	3.1	3.2	2.8	3.0
Leucine	6.1	5.5	5.8	6.1	5.3	5.7
Tyrosine	3.3	2.8	3.1	3.6	1.6	2.9
Phenylalanine	5.6	5.0	5.4	6.2	5.0	5.4
Available lysine	4.1	3.9	4.0	4.2	3.9	4.1

[1]Sources of varieties noted on Table 10.

Bell and Stipanovic (1977) pointed out that although gossypol must be eliminated for cottonseed to become a major source of high protein food and feed, the pigment glands confer host resistance to many insects and herbivores. Flavonols, such as catechins, procyanidins and condensed tannins are also involved in resistance to several diseases (Chapter 38). The pigments decrease the need to apply costly insecticides, and optimal combinations of terpenoids and flavonoids for host plant resistance are being sought.

The alternative is to grow glandless cottons in areas such as the Texas High Plains and parts of California where insect pests are not a serious problem in cotton farming. Glanded cottons would be grown in locations where such insects as bollworms and bollweevils are problems. Another possibility would be to breed cotton plants with the genetic character called "delayed gland morphogenesis", a character mainly noted in certain wild species (Lukefahr and Fryxell, 1967). The initial cells for gland formation occur in the seed embryos, but there is no deposition of gossypol until they begin to germinate. All other aerial portions of the cotton plant (leaves, stems, bolls) have as many glands and as much gossypol as present commercial varieties.

COMPARISON OF SEED QUALITY DATA DEVELOPED THROUGH THE YEARS

The protein and oil composition of moisture-free, delinted cottonseed has not changed very much over the years (Tables 1-5, 7-10). For example, Pope and Ware (1945) found oil content of 16.1 to 26.7 percent and protein content of 20.5 to 26.8 percent. Thirty years later, Lawhon *et al.* (1976) found oil content to be 16.5 to 25.6 percent, and protein content to be 19.6 to 24.0 percent. Turner *et al.* (1976a) reported average values of 19.6 percent for oil and 24.8 percent for protein. On a moisture-free kernel basis Stansbury *et al.* (1956) reported values for oil, protein and gossypol of 35.4 to 37.7 percent for oil, 39.3 to 40.6 percent for protein and 0.8 to 1.2 percent for gossypol. Pandey and Thejappas' (1975) averages for these same constituents were 32.8, 40.2 and 1.4 percent, respectively; Lawhon *et al.* (1976) published values of 37.8, 39.3 and 1.2 percent, respectively. These data show that although seed storage constituents can be influenced by cultivar, growing location and crop season, little has been done through the years to take advantage of this vast wealth of variability to improve cottonseed quality.

RECENT COTTONSEED QUALITY RESEARCH

A number of ways to improve cottonseed quality and augment the returns to the producers and processors of cottonseed, as well as influence the end-use value, have been identified (Table 13) (Carter *et al.*, 1979). In the latter part of the 1970's a cooperative effort was undertaken to develop a data base on the physical and chemical composition of cottonseed from select cultivars grown in different locations in the Cotton Belt. In California, the data base study included four Acala varieties grown during three crop seasons at four locations in the San

Table 13. Identified factors that affect the value of cottonseed (from Carter *et al.*, 1979).

Factor	Needed change
Gossypol	Lower or eliminate
Oil	Increase
Protein	Increase
Hulls	Decrease—improve resistance to mechanical and microbiological damage
Linters	Decrease
Cyclopropene fatty acids	Decrease or eliminate
Essential amino acids	Increase—especially lysine and methionine
Nongossypol pigments	Identify and remove flavonoids
Flavor	Identify and improve
Sugars	Remove raffinose and stachyose

Joaquin Valley. In Texas the seed of the four standard cultivars of the National Variety Tests grown at eight locations for one year and at four locations for three crop years were examined. The specific cultivars and locations are listed in the appropriate tables and figures.

Twenty-three seed quality characteristics of cottonseed were related to genetic and growing location, including moisture, seed index, hull, lint and kernel percentages, quantity and quality indexes, and grade, germinability, proximate composition (including oil, protein, carbohydrate, crude fiber and ash), free fatty acids, free and total gossypol, and cyclopropene fatty acids. The nitrogen solubility, differential settling tests and extractability of nonstorage and storage proteins were examined to evaluate the processability of cottonseed into food. Studies of fatty acids, amino acids and the polyacrylamide gel electrophoretic properties of proteins from cottonseed were also conducted.

Seed grade factors (quantity, quality index and grade) were determined by the rules of the National Cottonseed Products Association (1977-78). Tests for lint, proximates [protein (or nitrogen x 6.25), oil, carbohydrates, ash and fiber], free fatty acids, free and total gossypol and fatty acid profile were made in accordance with the official and tentative methods of the American Oil Chemists' Society (1976). The methods of Kaiser *et al.* (1974), Brown (1969), Rao *et al.* (1963), Lyman *et al.* (1953) and Vix *et al.* (1949) were used to determine protein amino acid profiles, cyclopropenoid fatty acids, epsilon-amino-free lysine, nitrogen solubility and differential settling, respectively. Nonstorage and storage protein extractability were determined by the selective extraction procedure of Berardi *et al.* (1969) with the following modifications: (1) the ratio of hexane-defatted flour to extractant (water, 10 percent NaCl solution) was 1:20 (w:v), and (2) a 10 percent NaCl solution was used to solubilize storage proteins. The method of Lowry *et al.* (1951), with serum bovine albumin as the standard, was used to determine quantity (mg/ml) of extractable protein. Polyacrylamide disc-gel electrophoresis of nonstorage and storage proteins was conducted by the procedure of Cherry *et al.* (1970).

RESULTS BY LOCATIONS

The analysis of variance showed that agronomic and/or environmental factors influence most of the quality factors (Table 14). Significant location x cultivar interactions for most of the quality factors suggested that all cultivars did not respond the same across locations.

Texas Results—Among the four cultivars grown in Texas, Acala 1517-70 generally maintained the highest and Lockett 3789A the lowest percentages of oil (Figure 1) (Cherry *et al.*, 1978b,c). Oil contents among locations were consistently highest at the west (dry) and south (Subtropical and Coastal Bend) locations, and lowest in the north (High Plains and Rolling Plains) region. Significant variability in oil percentages was noted among cottonseed of all cultivars from

Table 14. F-test for each percentage quality factor of cottonseed (from Cherry *et al.*, 1978b).

Quality factor	Cultivar (C)[1]	Location (L)[1]	C X L[1]
df[2]	3	7	21
Hulls	4.79**	11.29**	1.58
Kernels	5.57**	19.65**	2.44*
Lint	74.79**	30.75**	7.33**
Quantity index	2.25	120.69**	3.22**
Quality index	9.35**	340.87**	4.96**
Seed grade	12.69**	294.95**	2.67**
Seed index	45.00**	24.98**	2.39*
Protein[4]	15.98**	6.76**	3.32**
Oil[4]	14.81**	23.38**	4.03**
Total sugars[5]	2.94*	2.74*	3.17**
Ash[5]	0.98	31.97**	3.18**
Crude fiber[5]	2.40	2.57*	0.43
Free fatty acids[6]	2.08**	585.59**	9.38**
Free gossypol[5]	18.10**	5.52**	6.64**
Total gossypol[5]	29.10**	15.86**	11.13**
ε-Free amino lysine[7]	2.73	6.72**	0.70
N-Solubility[8]	17.89**	5.11**	2.87**
Germinability	3.86*	73.25**	9.96**
df[2,3]	3	6	18
Cyclopropenoid fatty acids[5]	2.78**	26.14**	7.22**
Differential settling overflow:			
Protein	1.93	7.27**	2.22*
Free gossypol	35.70**	40.69**	9.30**
Total gossypol	22.40**	15.53**	1.92
Differential settling underflow:			
Protein	1.87	14.44**	7.68**
Free gossypol	8.92**	25.90**	5.37**
Total gossypol	10.57**	36.44**	6.44**
Protein extractability:			
Nonstorage	1.57	0.50	0.95
Storage	0.23	2.51*	1.27

[1]*,**Significant at the 0.05 and 0.01 level of probability, respectively, by the Newman-Keuls multiple range test (Steel and Torrie, 1960).

[2]Degrees of freedom.

[3]Pecos location omitted from these tests.

[4]Moisture-, lint-free basis.

[5]Moisture-free kernel basis.

[6]Percentage in oil.

[7]g/100g sample.

[8]Percentage of total protein.

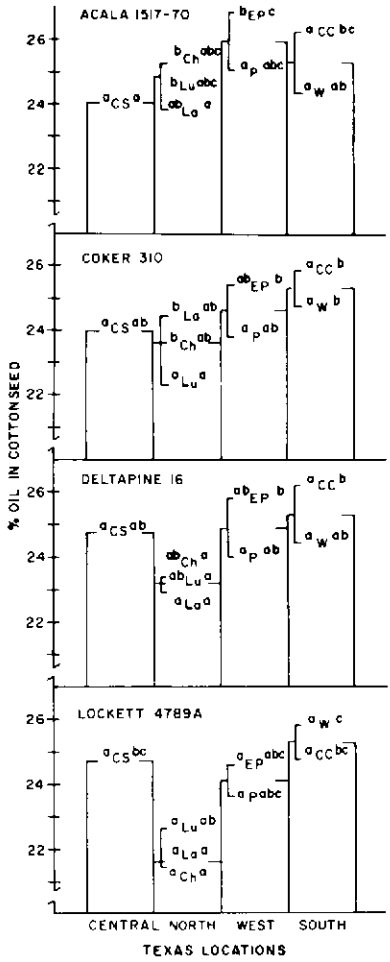

Figure 1. Mean values of oil in Texas-grown cottonseed (moisture-free, lint-free). CC, Corpus Christi; CS, College Station; Ch, Chillicothe; EP, El Paso; La, Lamesa; Lu, Lubbock; P, Pecos and W, Weslaco.

Chillicothe, Lamesa, Lubbock and El Paso.

The highest percentage protein for cottonseed occurred at College Station, and the lowest at Lubbock and Lamesa (Figure 2) (Cherry *et al.*, 1978b,c). Coker 310 generally had the highest percent protein among cultivars. Acala 1517-70 and Deltapine 16 showed the greatest differences among Texas locations, whereas Lockett 4789a displayed little variability.

Mean values for gossypol are shown in Figure 3. No consistent pattern for location over cultivars or cultivar over locations was readily evident. Apparently

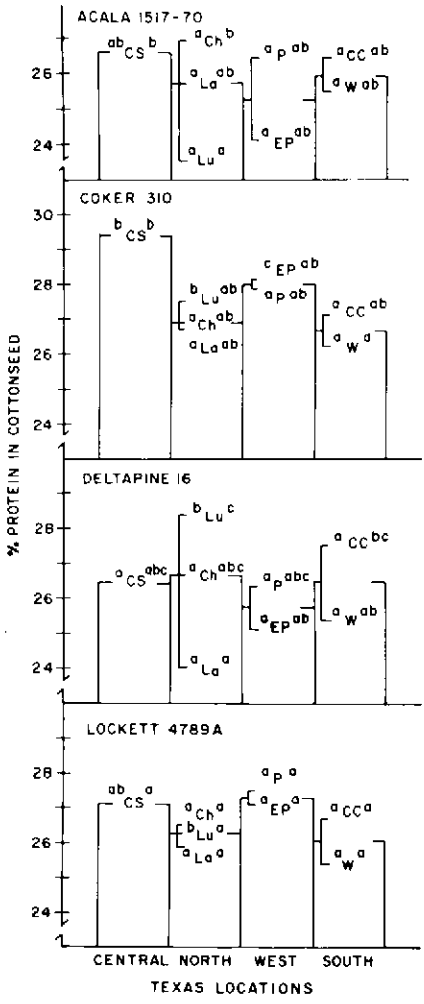

Figure 2. (Left) Mean values of protein in Texas-grown cottonseed (moisture-free, lint-free). (See Figure 1 for abbreviations.)

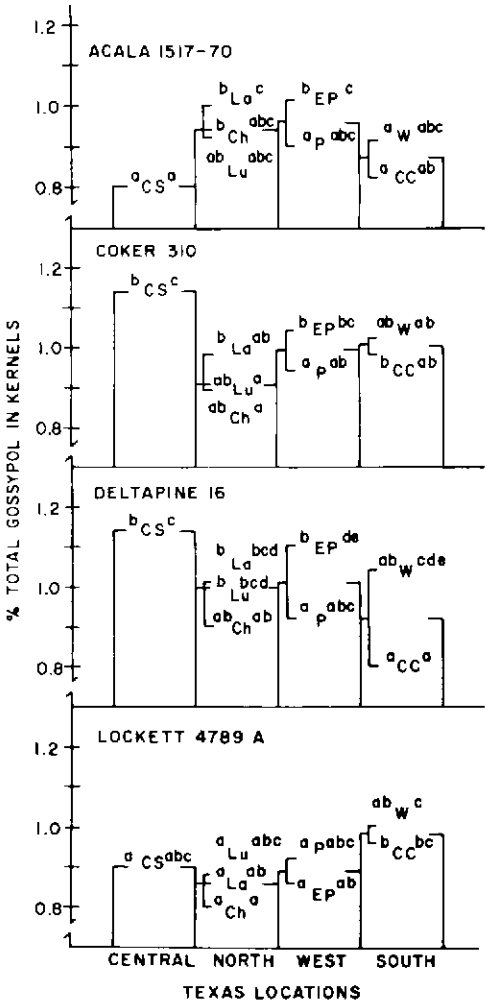

Figure 3. (Right) Mean values of gossypol in Texas-grown cottonseed kernels (moisture-free). (See Figure 1 for abbreviations.)

gossypol has a high environment x genotype interaction, as is indicated in Table 14.

The amino acid content of most of the cottonseed was significant or highly significant for the statistical variables of cultivar, location and/or cultivar x

Table 15. Amino acid composition (g/100 g sample) of fat-free cottonseed flour from cultivars grown in various Texas locations (from Cherry *et al.*, 1978b).

	Range of amino acids			F-test for percentage amino acids[3]		
Amino acid	Low	High	Mean	Cultivars (C)	Locations (L)	CxL
Alanine	1.00(C,W)[2]	2.26(L,EP)	2.12	2.306	0.432	1.137
Valine[1]	1.66(D,CS)	2.61(A,CC)	2.20	2.688	4.135*	3.005*
Glycine	2.08(A,Lu)	2.35(L,EP)	2.21	3.207*	1.608	0.966
Isoleucine[1]	1.20(D,CS)	1.86(A,C)	1.59	2.231	2.914*	2.399*
Leucine[1]	2.88(D,La)	3.84(C,W)	3.12	3.418*	3.504*	1.969
Proline	1.83(L,Lu)	2.13(A,CC)	1.96	1.463	1.476	0.610
Threonine[1]	1.42(A,W)	1.98(C,C)	1.74	6.412**	2.635*	1.797
Serine	2.14(D,La)	2.59(D,C)	2.40	3.971*	2.142	1.243
Methionine[1]	0.59(A,W)	0.96(C,W)	0.74	3.202*	1.391	2.201*
Phenylalanine[1]	2.62(C,W)	3.02(L,Lu)	2.82	1.996	0.719	0.989
Aspartic acid	4.58(D,EP)	5.25(L,La)	4.93	3.147*	3.773**	0.809
Glutamic acid	9.46(D,CC)	11.15(C,CC)	10.53	2.009	2.953*	1.131
Tyrosine	1.29(D,La)	1.68(C,CC)	1.51	4.036*	4.129**	1.754
Lysine[1]	2.28(D,EP)	2.63(L,EP)	2.46	3.832*	6.588**	1.791
Histidine[1]	1.12(L,CS)	1.62(D,Lu)	1.41	0.629	2.466*	4.985*
Arginine[1]	4.39(D,La)	6.42(C,CC)	5.43	2.099	5.384**	0.905
Half-cystine	0.70(L,EP)	1.08(C,CC)	0.88	8.038**	7.751**	2.112*
Total	44.34(D,La)	50.82(C,CC)	48.02	3.115*	2.376	1.105

[1]Essential amino acids with respect to their growth effect in the white rat.

[2]Cultivar and location. Cultivars: A, 'Acala 1517-70'; C, 'Coker 310'; D, 'Deltapine 16'; L, 'Lockett 4789A'. Locations: C, Chillicothe; CC, Corpus Christi; CS, College Station; EP, El Paso; La, Lamesa; Lu, Lubbock; P, Pecos; and W, Weslaco.

[3]*,**Significant at the 0.05 and 0.01 level of probability, respectively.

Table 16. Fatty acid composition (percentage) of oil from cottonseed kernels of cultivars grown in various Texas locations (from Cherry *et al.*, 1978b).

	Range of fatty acids			F-test for percentage fatty acids[2]		
Fatty acid	Low	High	Mean	Cultivars(C)	Locations(L)	CxL
Myristic (C14:0)	0.68(C,Lu)[1]	1.16(L,CC)	0.82	102.714**	81.937**	4.813**
Palmitic (C16:0)	21.63(A,Lu)	26.18(L,CC)	23.68	8.705**	96.801**	2.728**
Palmitoleic (C16:1)	0.56(D,CS)	0.82(A,CC)	0.65	29.786**	21.528**	2.328**
Stearic (C18:0)	2.27(L,C)	2.88(C,W)	2.55	3.540*	12.296**	1.621
Oleic (C18:1)	15.17(D,CS)	19.94(L,CC)	17.41	356.913**	79.995**	6.892**
Linoleic (C18:2)	49.07(A,CC)	57.64(C,Lu)	54.54	238.386**	229.044**	10.084**

[1]Cultivar and location. Cultivars: A, 'Acala 1517-70'; C, 'Coker 310'; D, Deltapine 16'; L, 'Lockett 4789A'. Locations: C, Chillicothe; CC, Corpus Christi; CS, College Station; EP, El Paso; La, Lamesa; Lu, Lubbock; P, Pecos; and W, Weslaco.

[2]*,**Significant at the 0.05 and 0.01 level of probability, respectively.

location (Table 15) (Cherry *et al.*, 1978b,c). Each of the cultivars had specific amino acids that were lower than in other cultivars, whereas Coker 310 and Lockett 4789A each accounted for 12 of the highest levels of specific amino acids. Variations in threonine and half-cystine had a strong genotype component. The latter amino acid was also strongly influenced by environment, as was lysine.

Most cottonseed oil fatty acid levels varied significantly for cultivar, location and cultivar x location (Table 16) (Cherry *et al.*, 1978b,c). Because of the percentage expression, a cultivar or location high in one abundant fatty acid would be low in another fatty acid.

Table 17. Mean values of cottonseed quality traits of 'Acala' cultivars grown at four California locations, 1975-1977.[1]

Quality factors[2]	'Acala' cultivars 'SJ-2'	'SJ-5'	Covariance	Lowest standard deviation
Hull	41.60a	36.89b	5.2	1.50
Kernel	45.37a	51.63b	3.5	0.96
Lint	19.03a	21.81b	4.9	1.01
Quantity index	97.29a	109.59b	1.0	3.00
Grade	96.73a	109.29b	1.3	3.30
Oil	19.03a	21.81b	1.2	0.64
Protein	22.25a	23.44b	1.8	0.11
Free fatty acids	1.20a	0.86b	2.4	0.44
Free gossypol	1.03a	0.73b	6.4	0.05
Total gossypol	1.09a	0.80b	5.7	0.04
Phosphorus	0.94a	0.88b	7.0	0.05
Differential settling overflow:				
Free gossypol	0.03a	0.02b	6.4	0.05
Total gossypol	0.06a	0.04b	5.7	0.04

[1]Means among cultivars having the same letter are not significantly different according to the Newman-Keuls multiple range test. Values for seed index ('SJ-2', 11.68; 'SJ-5', 11.16), crude fiber (2.20; 2.09), ash (5.07; 5.15), total sugars (6.65; 6.70), ε-free amino lysine (3.86; 3.85), N-solubility (97.46; 97.90), quality index (99.32; 99.74) and differential settling overflow protein (61.44; 61.06) were not significantly different for the two cultivars.

[2]Hull, kernel, and lint are presented as percentage (%) of seed; oil and protein are % of linted seed; free fatty acid is % of oil; free and total gossypol, phosphorus, crude fiber, ash and total sugars are % of kernels; ε-free amino lysine is g/100g flour; N-solubility is % of total protein; and differential settling overflow protein and free and total gossypol is % of flour. All of these values are presented on an "as is" moisture value, which was 9.35 and 9.08 for the 'Acala SJ-2' and 'Acala SJ-5' cottonseed, respectively, values that were not significantly different.

A summary of the effects of cultivar and growing location on all of the other seed quality factors included in these studies was presented by Cherry *et al.* (1978b).

California Results—Select data on cottonseed from Acala SJ-2 and Acala SJ-5 in California are presented in Tables 17, 18 and 19. Statistically significant improvements in seed quality of SJ-5 over SJ-2 include (1) both a reduced portion of the seed as hull and linters and an increase in the percentage of kernel, (2) decreased amounts of gossypol and cyclopropene fatty acids, (3) improved quantities of oil and protein and (4) higher levels of essential amino acids and select fatty acids (a decrease in palmitic acid and a subsequent increase in oleic acid).

Table 18. Mean values of amino acids of flour from cottonseeds of 'Acala' cultivars grown at four California locations, 1975-1977.[1]

Amino acid	'Acala' cultivars	
(g/100g flour)	'SJ-2'	'SJ-5'
Alanine	2.00a	2.03a
Valine[2]	2.10a	2.14a
Half-Cystine	0.79a	0.82a
Arginine[2]	6.47a	6.62a
Lysine[2]	2.24a	2.26a
Histidine[2]	1.50a	1.59b
Tyrosine	1.54a	1.54a
Aspartic acid	4.84a	4.84a
Glutamic acid	10.38a	10.40a
Phenylalanine[2]	2.68a	2.78a
Glycine	2.10a	2.12a
Isoleucine[2]	2.55a	2.57a
Leucine[2]	2.96a	3.01a
Proline	1.92a	1.95a
Threonine[2]	1.64a	1.67a
Serine	1.41a	1.43a
Methionine[2]	0.64a	0.66a

[1]Means among cultivars having same letter are not significantly different according to the Newman-Keuls multiple range test.

[2]Essential amino acid with respect to growth of rats.

Table 19. Mean values of fatty acids of oil from cottonseed of 'Acala' cultivars grown at four California locations, 1975-1977.[1]

Fatty acid (percentage)[2]	'Acala' cultivars 'SJ-2'	'SJ-5'	Covariance	Lowest Standard deviation
Palmitic (C16:0)	23.32a	22.69b	0.57	0.26
Palmitoleic (C16:1)	0.72a	0.64b	7.4	0.02
Stearic (C18:0)	2.17a	2.29b	3.2	0.07
Oleic (C18:1)	16.63a	17.26b	0.98	0.20
Cyclopropene	0.90a	0.84b	2.7	0.04

[1]Means among cultivars having the same letter are not significantly different according to the Newman-Keuls multiple range test.

[2]Values for myristic (C14:0), ('SJ-2', 0.75; 'SJ-2', 0.74), linoleic (C18:2), (55.80; 55.84), and linolenic (C18:3), (0.35; 0.34) acids were not significantly different for the two cultivars.

Acala Cottonseed Quality In California And Texas—Percentages of oil in cottonseed of Acala cultivars SJ-2, SJ-4 and SJ-5 grown at four locations in California ranged from 20 to 27 percent , and that of Acala 1517-70 from eight areas in Texas was 24 to 26 percent (Figure 4) (Cherry *et al.*, 1979b). Average oil content of all samples of Acala cottonseed from the two states was approximately 25 percent for Texas and 24 percent for California. By Newman-Keuls multiple-range analysis (Steel and Torrie, 1960) only the highest value (SJ-5 grown at Huron, California) was significantly different from all values less than 24.5 percent.

The protein content of cottonseed from Acala 1517-70 grown in Texas ranged from 24.5 to 26.6 percent (Figure 5) (Cherry *et al.*, 1979b). In California, values ranged between 26 and 29 percent. The overall average for Texas-grown cottonseed was 25.6 percent, that for California 26.6 percent. Most of the values were not significantly different; however, percentage of protein from SJ-2 grown at Wheeler Ridge was significantly different from values below 25.2 percent.

Acala SJ-2 cottonseed from all locations of California had higher percentages of total gossypol (1.08 to 1.27 percent) than the other Acala cultivars, SJ-4, SJ-5 and 1517-70 (Figure 6) (Cherry *et al.*, 1979b). The average of gossypol content in all samples from California and Texas were 1.0 and 0.9 percent, respectively.

These data show that during the past ten years, since the development of Acala SJ-2, the breeding program in California has selectively increased oil and protein content in Acala cottonseed (SJ series) and reduced gossypol (see Figures 4, 5 and 6.).

A significantly higher level of lysine (2.67g/100g of hexane-defatted flour) was noted for Acala SJ-4 cottonseed than from those of the other Acala cultivars;

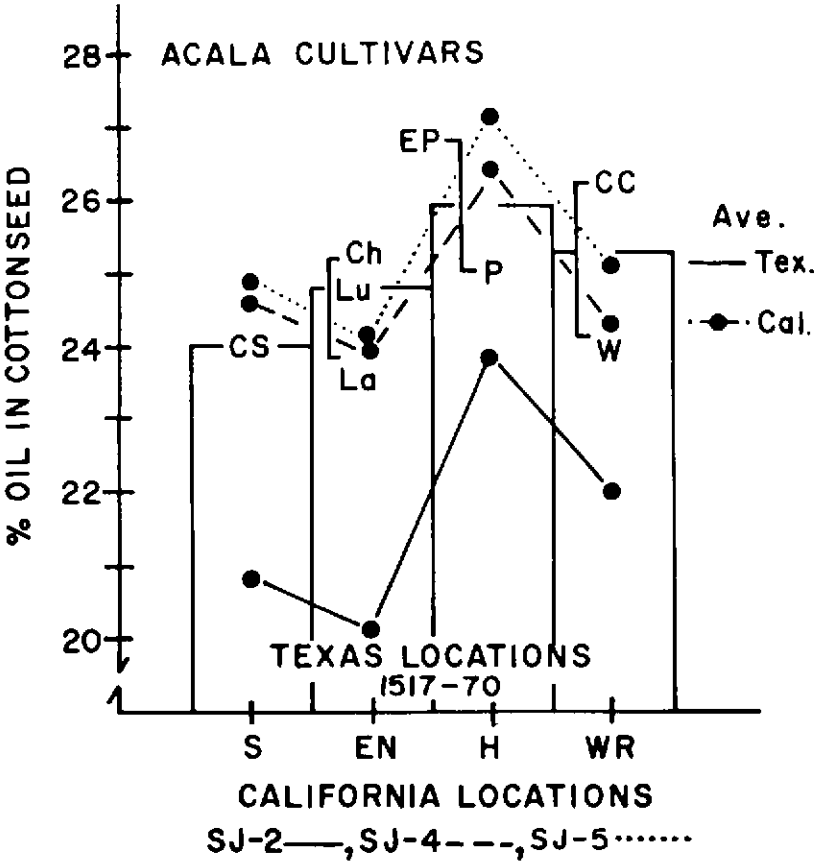

Figure 4. Cottonseed (moisture-free, lint-free) oil content from 'Acala' cultivars grown in Texas and California. California: EN, El Nido; H, Huron; S, Strathmore, and WR, Wheeler Ridge. Texas: CC, Corpus Christi; CS, College Station; Ch, Chillicothe; EP, El Paso, La, Lamesa; Lu, Lubbock; P, Pecos; and W, Weslaco. (From Cherry *et al.*, 1979b).

all other lysine values in cottonseed flours from cultivars grown in California ranged between 2.14 and 2.34 (Figure 7). The lysine content of flour from Acala 1517-70 grown in Texas ranged between 2.31 and 2.62. The average lysine values for all California and Texas samples were approximately 2.32 and 2.42, respectively.

Among the sources of Texas-grown cottonseed, flour of Acala samples from College Station had significantly higher amounts of methionine than samples from other locations (Figure 7). Cottonseed flours from the other Texas locations contained similar amounts of methionine, ranging from 0.6 to 0.7g/100g of

sample. California-grown cottonseed produced flours containing between 0.64 and 0.80g of methionine/100g of sample. The overall average methionine content of flours from California cottonseed was slightly higher than those from Texas.

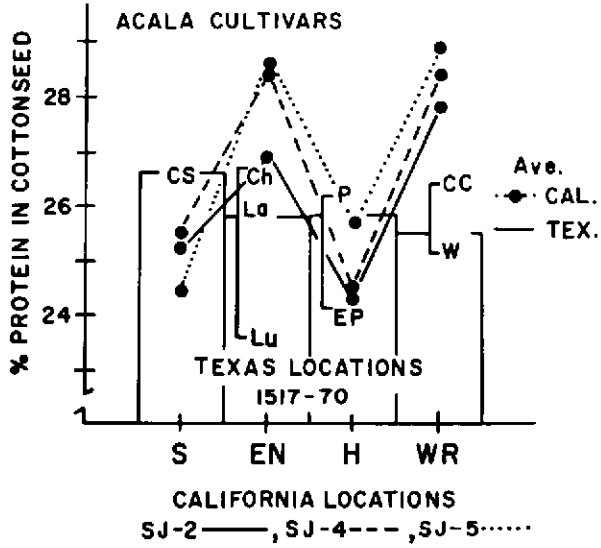

Figure 5. Cottonseed (moisture-free, lint-free) protein content from Acala cultivars grown in Texas and California (from Cherry *et al.*, 1979b). (See Figure 4 for abbreviations.)

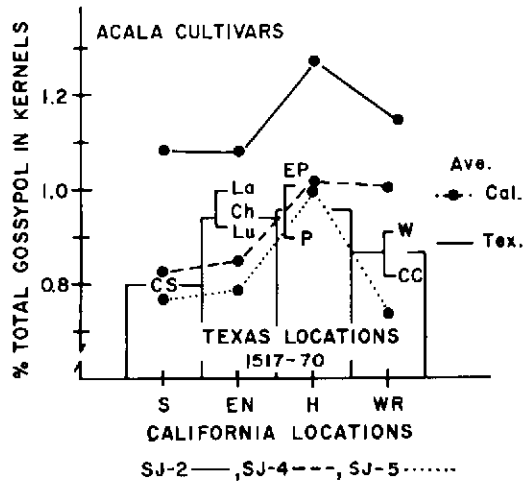

Figure 6. Total gossypol content in cottonseed kernels (moisture-free) of 'Acala' cultivars grown in Texas and California (from Cherry *et al.*, 1979b). (See Figure 4 for abbreviations.)

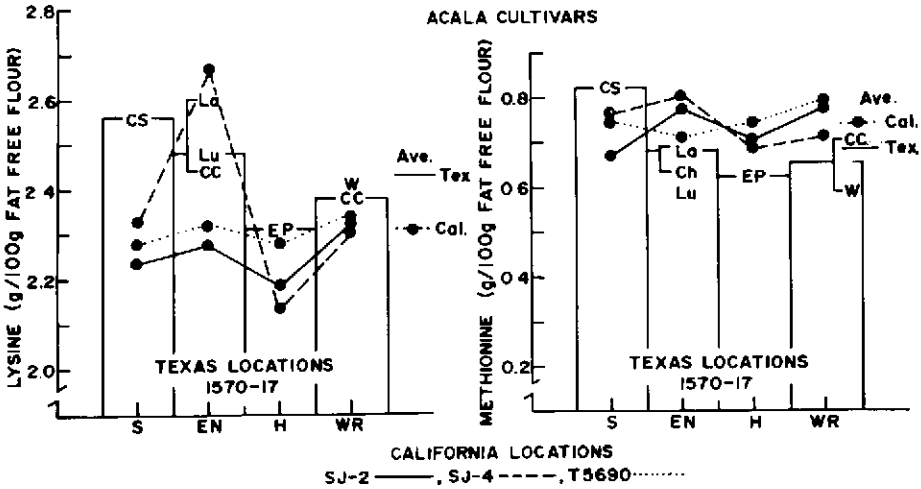

Figure 7. Lysine and methionine content of hexane-defatted flour ("as is" moisture) of cottonseed from Acala cultivars grown in Texas and California (from Cherry *et al.*, 1979b). (See Figure 4 for abbreviations.)

OTHER FACTORS AFFECTING COTTONSEED QUALITY

PINK BOLLWORM CONTAMINATION

Cultivars of *Gossypium hirsutum* L. and *G. barbadense* L. are susceptible to pink bollworm [*Pectinophora gossypiella* (Saunders)] and require application of insecticide to insure that growers will receive adequate compensation for their fiber and seed. Field infestation levels of approximately 50 percent, with no more than one larva per boll, have little effect on cotton-quality (Brazzel and Gaines, 1956, 1957), but infestation levels of 60 percent or greater causes a decrease of as much as 34 percent in the cotton crop because of lower yields and poorer fiber and seed quality (Lukefahr and Martin, 1963).

Cherry and Goodwin (1978) showed that pink bollworms affect the physical and chemical composition of cottonseed, and therefore, the processability of cottonseed into functionally and nutritionally useful food and feed ingredients. As the number of pink bollworms per boll increased from 0 to 12, the level of oil, protein and free and total gossypol tended to decrease. Pink bollworm contamination also caused fluctuations in fatty acid and essential amino acid content—quality was highest in bolls containing 0 and 5-6 insects. Extractability of nonstorage and storage proteins fluctuated between high and low quantities in cottonseed from bolls containing 0 to 5 pink bollworms but decreased as infestation increased to 12 insects. Polyacrylamide gel patterns showed that changes oc-

curred in the type of protein present in water and alkaline pH extracts. No doubt biochemical mechanisms operating in the cottonseed during development are being affected by the pink bollworms in the boll, and this in turn affects the quality of cottonseed available for food and feed processing.

MODULE STORAGE OF SEED COTTON

The module builder, which allows field storage of seed cotton prior to ginning, is revolutionizing the cotton industry by breaking the connection between harvesting and processing, allowing each operation to proceed at its own pace (Wilkes *et al.*, 1972; Wilkes and Sorenson, 1973; Roberts *et al.*, 1973; Curley *et al.*, 1973; Paxton and Roberts, 1973; Baskin, 1976a; Jones, 1976; Kepner and Curley, 1976; Eickhoff and Willcutt, 1978; Wilkes, 1978). Roberts *et al.* (1973), Paxton and Roberts (1973), Eickhoff and Willcutt (1978) and Wilkes (1978) showed that the germinability and free fatty acid content of high-quality cottonseed are not affected significantly during module storage of seed cotton as long as seed moisture remains below 12 percent. Low quality seed deteriorates regardless of moisture level. The moisture in such trash as leaves, soil and branches causes "hot spots", localized temperature rises in the module which transfer to the seed. Temperatures that exceed 50C during module storage indicate that seed is deteriorating and that it should be ginned immediately. Good management during harvesting and close monitoring of the conditions of the seed cotton during storage are necessary for module storage (see Chapter 32).

Cherry *et al.* (1979a) supported earlier studies showing that high temperature and moisture affected cottonseed quality during module storage. Under the right conditions, microorganisms such as *Aspergillus, Mucor* and *Alternaria* that exist in the microflora of cottonseeds may also affect their quality. Cottonseeds having greater than 12 percent moisture seemed to be most susceptible to changes in composition. The most notable changes were decreases in percentages of oil and free gossypol and increases in levels of free fatty acids. The addition of propionic acid to moist, module-stored seed at a rate of 4 lb/bale lessened these changes. Increases in protein may be a result of the proportional decrease in oil. The extractability of nonstorage protein was not significantly different among samples stored dry or moist, but these values were significantly lower than those of samples that were not stored or that were stored with propionic acid. Great variability was noted only in the extractability of storage proteins from cottonseed stored moist. Gel electrophoretic patterns showed no qualitative or quantitative differences in extracts of nonstorage and storage proteins from stored and unstored cottonseeds; variations may be below levels detectable with techniques used in these studies.

COTTONSEED MATURITY, CLOSED-BOLL HARVESTING, AND ARTIFICIAL DRYING OF COTTONSEEDS

Changes in the constituents of maturing cottonseeds and the factors that affect

the rate of their synthesis have been investigated for many years (Gallup, 1932; Grindley, 1950; El-Nockrashy *et al.*, 1976; Benedict *et al.*, 1976; Sood *et al.*, 1976; Elmore and Leffler, 1976; Leffler *et al.*, 1977; Kajimoto *et al.*, 1979; Cherry *et al.*, 1980). Protein, oil and gossypol are deposited continuously in the cottonseed through most of the period between flowering and opening of the bolls.

Benedict *et al.* (1976) used ^{14}C isotope to follow the rate of incorporation of radioactively labeled photosynthate of leaves into various seed storage components. The amount of radioactive label incorporated into amino acids remained fairly constant throughout boll development, indicating that few changes were occurring in the rate of synthesis of different amino acids. Elmore and Leffler (1976) also noted no drastic shifts in the concentration of any amino acid during seed maturation. Benedict *et al.* (1976) noted no large shifts in ^{14}C labeling of structural proteins to storage globulins, but Elmore and Leffler (1976) showed that aspartic acid was predominant early in seed development and was then replaced by arginine and glutamic acid, amino acids mainly present in storage proteins.

Leffler *et al.* (1977) showed that maturing cottonseed do respond to elevated nitrogen fertilization by synthesizing additional storage proteins (see Chapter 30). Such responses cause significant changes in the seeds' amino acid composition: lysine, threonine, glycine and alanine decreased, while arginine and glutamic acid increased (arginine and glutamic acid are mainly present in cottonseed storage globulins).

It was shown that the rate of oil synthesis did not increase dramatically until the seeds had matured 20 days after the flowering stage (Benedict *et al.*, 1976; Kajimoto *et al.*, 1979). The rate of oil synthesis peaked between 30 and 40 days and stopped by 45 days. The total amounts of cyclopropene and cyclopropane fatty acids in triglycerides were 38.0 and 15.9 percent of fatty acids, at 3 and 10 days, respectively, after flowering (Table 20) (Kajimoto *et al.*, 1979). These fatty acids decreased markedly from 10 to 65 days (when the seeds were considered mature). Linoleic acid increased rapidly during this same period. Linolenic acid, a highly unsaturated and oxidatively unstable fatty acid, decreased from 13.5 percent to non-detectable levels during this same time. The potential for causing the greatest reduction in cyclopropane and cyclopropene fatty acids and improving quantities of linoleic acid by maneuvering environmental conditions (and, in turn, manipulating favorable biochemical mechanisms into operation in the maturing cottonseed) is probably best during the time of maximum oil synthesis.

Harvesting unopened bolls and opening them by artificial drying methods were investigated by Jones *et al.* (1977). This approach to processing seed cotton: (1) reduced dust in the cotton fiber; (2) lessened the need for control of boll rot organisms; (3) shortened the growing season, offering the potential of multiple-crop production; (4) lessened harvested trash in the lint; and (5) introduced the possibility of utilizing never-dried fibers in the textile industry. This study showed that cotton could be harvested as much as 30 to 40 days before all bolls opened in

Table 20. Fatty acid composition (percentage) in oil of maturing cottonseed. (Summarized from Kajimoto *et al.*, 1979.)

	Days after flowering			
Fatty acid	3	10	30	65
Myristic (C14:0)	0.3	0.7	1.4	1.4
Palmitic (C16:0)	15.2	27.9	27.4	28.3
Palmitoleic (C16:1)	0.6	0.9	1.0	0.8
Stearic (C18:0)	1.4	1.0	2.1	1.7
Oleic (C18:1)	17.5	12.9	13.7	15.9
Linoleic (C18:2)	18.3	35.3	50.1	50.7
Linolenic (C18:3)	13.5	5.0	Trace	—
Cyclic octadecanoic Acid (CP18:0)	7.4	3.1	1.2	0.3
Cyclic octadecenoic Acid (CP18:1)	9.2	3.7	1.1	0.3
Cyclic nonadecanoic Acid (CP19:0)	3.6	2.0	0.6	0.2
Cyclic nonadecenoic Acid (CP19:1)	17.8	7.1	1.5	0.4

the field without significant reductions in fiber yield and percentage of seed germination.

Simmons *et al.* (1979) and Cherry *et al.* (1980) showed that cottonseeds from hand harvested closed bolls that were dried artificially by blowing low humidity, 40C-air over them had oil and protein of more uniform quality than field-opened bolls. Averaged values of experiments from two crop years showed that seeds of closed bolls were smaller than those of field-dried bolls, but they were comparable in oil and protein content and the overall quality of fatty and amino acids. Seeds from closed bolls contained less free fatty acids, unsaturated fatty acids and cycloprene fatty acids than field-dried seeds. The composition of seeds from closed bolls harvested more than 45 days after flowering was not affected by maturing level and drying methods as much as that of more immature seeds.

Other drying methods included in these studies were lyophilization, forced air at 80C and microwave heating (Cherry *et al.*, 1980). Optimum quality was obtained in seeds from bolls dried by forced air at 40C and by lyophilization. The composition of maturing cottonseeds was altered significantly by oven drying at 80C and by microwave heating. These methods caused a decrease in total and free gossypol and in the extractability of nonstorage and storage proteins at most stages of seed maturity (seeds matured beyond 45 days after flowering were not affected as much as more immature seeds). Gel electrophoresis showed that cottonseed proteins were greatly denatured by these drying methods. Oven-dried seeds had lower percentages of oleic acid in the oil compared to those dried at

40C, lyophilized or field dried. Little change was noted in the overall quality of amino acids in oven-dried and microwave-dried seeds.

WILD *GOSSYPIUM* SPECIES

The wild species of *Gossypium* are excellent sources of diverse germplasm coding for new compositional properties (in protein, oil, and so forth) that may expand the functional and nutritional properties of cottonseed products as food and feed ingredients (El-Nockrashy *et al.*, 1969; Cherry *et al.*, 1970, 1971, 1972, 1977; Cherry and Katterman, 1971; Johnson and Thein, 1970; Cherry, 1977, 1978). The genus *Gossypium* is comprised of about 34 diploid and 4 natural allotetraploid species (see Chapter 1). The diploid (2n) plants are divided into six groups or genomes labeled A to F. Tetraploid (4n) species, from which presently cultivated varieties have originated, are described as 2(AD)n since they are

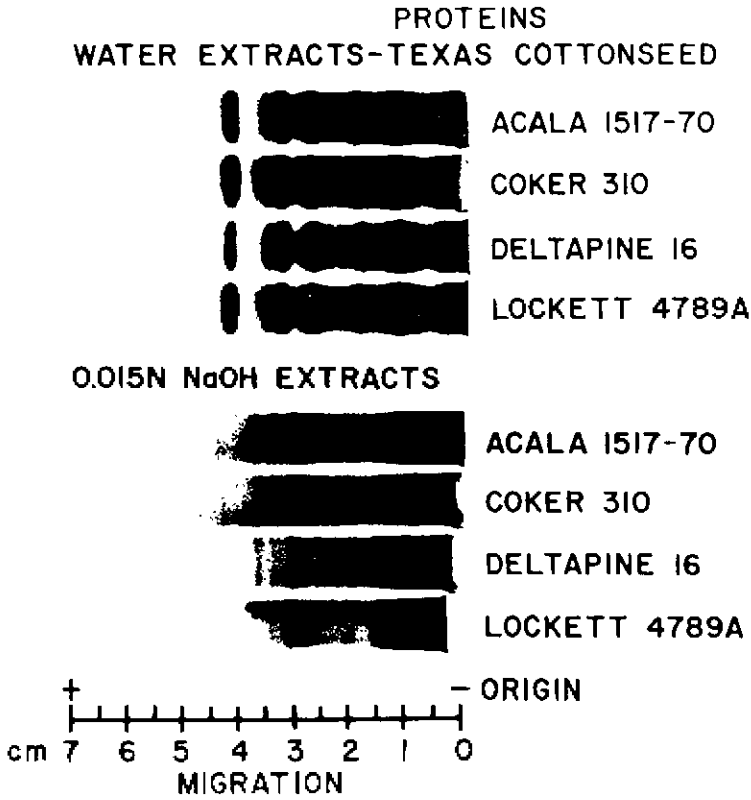

Figure 8. Typical polyacrylamide disc-gel electrophoretic patterns of proteins in cottonseed of Acala cultivars grown in Texas and California (from Cherry *et al.*, 1978c).

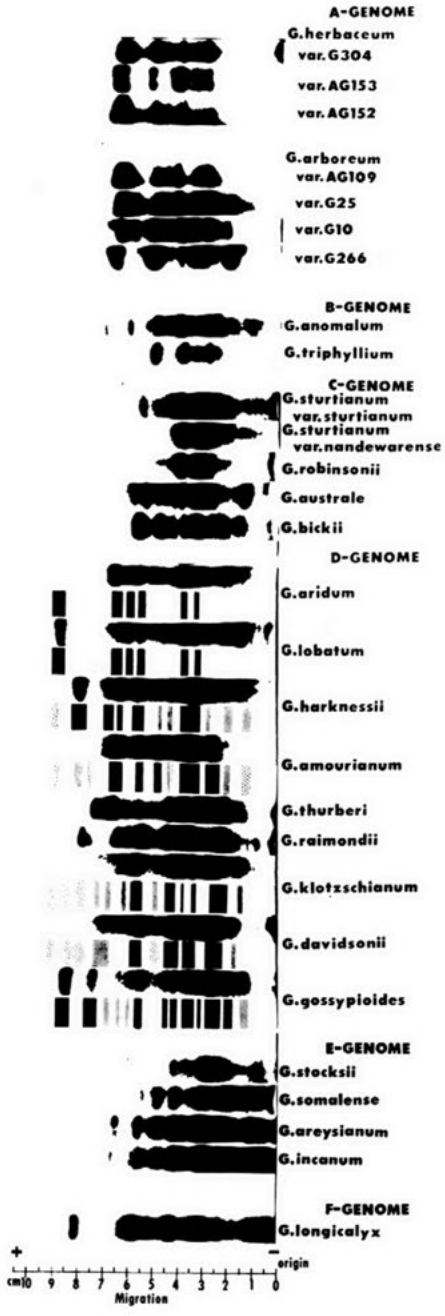

Figure 9. Gel electrophoretic patterns of proteins in cottonseed from select wild species in the genus *Gossypium* (from Cherry *et al.*, 1970).

hypothesized to have originated from a cross between plants from the A and D genome. Polyacrylamide gel electrophoretic studies show that much more variation (quantitative and qualitative) in banding patterns of proteins exist within the wild species of the A and D genomes than the cultivated varieties (Figures 8 and 9). Although the protein quality of cottonseed from different cultivars differs and can be influenced by genetic and agronomic practices, the gel electrophoretic data suggest that this variability is not reflected in the types of cottonseed protein. Thus, proteins that may be low in specific essential amino acids are unknowingly selected for in present-day breeding and agronomic programs to improve fiber quality, thereby perpetuating a nutritional imbalance in the cottonseed of new commercial cultivars.

The potential economic value of the wild relatives of *G. hirsutum* and *G. barbadense* is apparent not only because they offer important sources of diverse germplasm for improving agronomic characteristics but also as sources of protein material that offer the potential of expanding the functional and nutritional properties of cottonseed used in feed and food.

IMPROVING COTTONSEED USE IN FEED AND FOOD

Increased use of other seeds (such as soybean, palm, sunflower, peanut) in the oil and feed industry, and the even greater prospect for use of cottonseed as a food, have increased the awareness of the importance of cottonseed to feed and food reserves of the world. To keep cottonseed commercially competitive in the world market as a source of oil, feed and food, researchers have to strive continually to produce cottonseed with high oil and protein content and low to zero gossypol levels. In the oil, cyclopropenoid fatty acids should be eliminated, the amount of unsaturated fatty acids (especially oleic and linoleic) needs to be increased, and the amount of saturated fats should be reduced. In the proteins, the essential amino acids (especially lysine, methionine and isoleucine) should be increased. This could be done by selectively increasing quantities of the water-soluble non-storage proteins, or by improving the levels of select polypeptides in the storage globulins that are rich in essential amino acids (Cherry *et al.*, 1978a; King and Leffler, 1979; Zarins and Cherry, 1981). Whichever approach is taken, the effort should maintain the separation of these two groups of proteins into noncompartmentalized and compartmentalized, water- and alkaline-pH-extractable components, respectively (for reasons of economy and for diversification of protein product uses).

Techniques of processing of cottonseed to oil and meal, and liquid cyclone (Gardner *et al.*, 1976; Cherry *et al.*, 1978b,c, 1979b) and air classification (Friedman *et al.*, 1979) methods to prepare low gossypol edible food ingredients would be more applicable or economically feasible than under present conditions, if the amount of linters, hulls and gossypol in cottonseed were lowered. Lowering or eliminating gossypol in the meal would allow more use of cottonseed products

in the nonruminant animal and poultry industries. Removing linters would allow development of the direct dehulling of cottonseed during oil mill processing and not only eliminate a costly step in processing but also greatly reduce the dust problem.

Geneticists, agronomists, chemists and processing engineers have laid the groundwork for developing answers to many of the needs confronting the cottonseed industry. Their studies show that seed storage constituents can be influenced by cultivar, growing location and insect damage. Careful selection of cultivars and growing locations should yield optimum quality cottonseed products that can continue to compete favorably in the world market, without affecting the fiber industry.

DISCUSSIONS

THE GENETICISTS' VIEWPOINT

Interest in improving cottonseed quality has been traced to the work of Williams (1906). Throughout the intervening years, numerous authors have reported similar interests and research (Hare, 1914; Rast, 1917; Sievers and Lowman, 1932; Hancock, 1942; Pope and Ware, 1945; and Harland, 1949). Nevertheless, there has been neither continuity of interest nor continuity in research programs. There is no evidence that cottonseed quality has had an impact on cotton variety improvement. But we have now entered into a new period of interest in cottonseed quality that has been heightened by the discovery of the glandless factors (McMichael, 1959).

The role of geneticists is to develop the materials or information that will enable others to genetically manipulate cottonseed quality characters. They may participate in the identification and selection of the seed quality characters, but their primary function is to determine whether or not they can be genetically manipulated and how. Their initial task is to identify genetic variability for the seed quality characters (the existence of genetic variability is prerequisite to any genetic manipulation). Although in practice geneticists would have to identify and take into consideration the environmental variability, in this part of the discussion it is assumed that they have adequate control and understanding of the environment. Thus, this discussion will concentrate on the genetic variability.

The sources of natural variability available to Upland cotton researchers are (1) current cultivars, (2) the Upland germplasm collection at Stoneville, Mississippi, (3) the *Gossypium hirsutum* race collection at College Station, Texas, and (4) the *Gossypium* species collection at College Station, Texas. These sources are listed in order of increasing genetic variability, increasing difficulty to obtain and decreasing agronomic potential.

The species are perennial wild plants that are photoperiodic or at least respond to some specific environmental stimulus that controls flowering. A reasonably optimistic time to expect the transference of a character from the species to a

cultivar would be about 15 years. The *G. hirsutum* races are predominantly photoperiodic, and accessions range from types with strong perennial growth habit to prolific types that flower in the first year of growth. They produce spinnable fibers on their seeds but are agronomically unimproved, compared to modern cultivars. Transference of a character from the races to a cultivar should require about 10 years. The upland collection at Stoneville, Mississippi, represents strains and obsolete cultivars that have limited agronomic improvement relative to current cultivars but are readily accessible for genetic manipulation. Transference of a character from this source to a cultivar should require approximately five years. Current cultivars represent the most accessible source of genetic materials, if they possess the necessary variability.

Although this discussion is on various seed quality characteristics, it would have to give priority in genetics or plant improvement research to oil, protein and gossypol. These characters are immediately relevant to current cottonseed utilization, and acceptable methods and means to measure them are available. Once geneticists develop an understanding of these genetics, they will be better equipped to investigate other seed quality characteristics.

There is no need to discuss seed gossypol at length because with the discovery of the glandless genes (McMichael, 1959), geneticists have obtained the ability to genetically control the presence or absence of gossypol in seeds. Simple genetic control of seed gossypol has not solved all the problems. But most of the many questions yet to be answered, before geneticists can effectively access the role of glandless cottonseed, are not related to the genetics of seed quality (Kohel, 1978a).

The upland and race germplasm collections were screened for seed oil percentage (Kohel, 1978b) and seed protein percentage. These screenings revealed, as predicted, that greater variability existed in the race collection than in the upland collection. These studies included seed physical properties and stressed the importance of monitoring these properties. Differences in composition percentages can be due to changes in seed or seed coat size. These changes may be most important when transferring characters from diverse germplasm sources where geneticists observe the greatest range in seed physical properties (Kohel, 1978b).

The geneticists have concentrated on the transference of seed oil percentage from the germplasm collections because they have instrumentation that nondestructively measures seed oil. They are exploiting the variability of the germplasm collections because it is an activity that is well suited to pursue, and it is not easily undertaken by individual plant breeding programs. The goal of geneticists is to provide a range and combination of seed quality characters for use in plant breeding programs, characters not available in cultivars of acceptable agronomic background.

Seed oil percentages from the upland germplasm collection are quantitatively inherited and to a large extent controlled by additive gene action (Kohel, 1980).

At this point, the large environmental variance must be considered. In the segregating material studied, about two-thirds of the variability in seed oil percentage was due to the environment. However, as the range of seed oil percentage types was transferred into improved agronomic backgrounds, it reduced the range of seed oil percentage. The upland germplasm collection had a wider range of seed oil and physical properties than the cultivars.

INDUSTRY'S VIEWPOINT

Work by Cherry *et al.* (1978b), and presented in this text, has helped summarize the recent information on cottonseed quality. The distressing observation that there has been little if any change in oil, protein and gossypol levels in cottonseed in this century must be taken in context.

Cottonseed value has often been improperly assessed by the cotton industry. Cotton producers have concentrated their production and harvesting practices in order to maximize returns on lint per acre. For many years cottonseed was actually considered only a byproduct of little value to the grower. But several factors have combined to emphasize the value of cottonseed to the cotton producer, economic factors as well as educational efforts by the crushing industry. The fuzzy seed is, of course, the raw material of the cottonseed oil mill and its value reflects the values of the products that can be made from it.

The National Cottonseed Products Association, through its Research and Education Committee, has established the following goals for improving seed quality: (1) to increase seed yield per acre; (2) to increase the oil percentage; (3) to eliminate cyclopropenoid fatty acids in seed; (4) to eliminate or reduce seed gossypol; (5) to increase seed protein percentage; (6) to increase lysine content of meal; (7) to improve the level of mycotoxin resistance in seed; and (8) to insure that new cultivars have hulls that will maintain their integrity prior to the actual hulling operation (commonly called non-shattering). Another goal, (9) to reduce cottonseed linters percentage, is also included on this list, but we will not discuss it at this time.

Seed Yield—The oilseed crushing industry has always been concerned about the availability of cottonseed for crushing. Three possible avenues for improvement are theoretically available: (1) to increase the seed percentage in seed cotton, (2) to increase cotton acreages, and (3) to increase the total yield of seed cotton per acre. Increasing seed percentage of seed cotton would likely reduce lint yields, which is unacceptable. Increasing acreage as well as total seed cotton yield are the only two approaches to this problem. The cottonseed processing industry is cooperating with federal and state research workers in the development of superior cultivars and improved cultural practices and handling methods. Public and private breeding programs are providing germplasm that is superior in lint and seed quality and quantity, and also possesses resistance to disease and pests.

Oil—Modern cotton breeding programs include consideration of both oil and protein percentages. Breeders are reporting genetic variations within their breeding stocks for both of these characteristics. Variations between commercial cultivars produced during 1979 in California are shown in Table 21. The oilseed crushing industry encourages cotton breeders to increase both recoverable oil and seed protein levels in their new cotton lines.

Table 21. 1979 California cottonseed variety test means from four locations each at the San Joaquin and Imperial Valleys.

Analysis (percentage)[1]	San Joaquin Valley[2]		Imperial Valley
	'Acala SJ-2'	'Acala SJ-5'	'Deltapine 16'[3]
Protein	21.2	22.8	20.6
Oil	17.7	20.2	17.3
Total gossypol	1.28	.95	1.12

[1]"As is" moisture, fuzzed seed basis.

[2]Planting seed sold, 1980: 81% 'SJ-2,' 19% 'SJ-5.'
Planting seed sold, 1978-1979: 70-75% 'SJ-2', 25-30% 'SJ-5.'

[3]90% of cotton acreage in Imperial County, Calif., in 1980 was 'Deltapine 16'. The county produces about 7-10% of the Calif. cotton crop.

Cyclopropenoid Fatty Acids—The cyclopropenoid fatty acids are unique, biologically active fatty acids that are present in minute quantities in cottonseed oil. Cyclopropenoid fatty acid levels are an important consideration in meal as well as oil. Lack of a satisfactory analytical method has limited research in this area. Obviously, cottonseed processors would encourage any program that attempts to eventually identify low cyclopropenoid fatty acid strains of cotton and incorporate them into commercial lines.

Gossypol—Elimination of seed gossypol is one of the most important goals of the cottonseed products industry as well as other segments of the cotton industry. The first glandless cotton was reported by McMichael (1959). Glandless cultivars of cotton are now available with lint and seed production that is essentially equal to glanded types in lint yield and other characters. Low-gossypol meal has resulted in excellent performance in poultry, swine and pet rations. Potential food uses include protein supplementation as flour in baked goods, confectionery products and extenders in dairy and meat products. Food-grade glandless cottonseed products must meet Food and Drug Administration regulations.

The National Cottonseed Products Association is presently working with cotton breeders from the federal government, state universities and industry to promote the production of glandless cotton. Several glandless cultivars are now available for commercial production in West Texas. Breeders in California and the Southeastern United States are presently developing cultivars that provide excellent seed and lint yields.

Protein—Seed protein content is like oil content; increased levels of each are desirable.

Lysine—Levels in cottonseed meal have long been of concern to nutritionists. It is believed that it is possible for plant breeders to select lines capable of providing higher levels of this essential amino acid (as was accomplished in corn). Thus, cotton research workers are encouraged to include inprovement of lysine levels in their breeding programs.

Hull Integrity—The ability of the seed coat to resist shattering is a problem most obvious in the milling process. Cotton breeders have identified plant selections with wide variations in seed coat strength and thickness. Crushing mills are concerned that new cultivars retain their integrity because reduced seed coat thickness and strength can lessen the recovery of oil from meats and meal. Breeders should avoid reducing seed coat thickness and strength.

Communicating these goals to plant breeders has always been considered a weak point in the cottonseed industry. An example is a rise in gossypol levels seen in the California Acala varieties. During the early 1970's, California changed Acala cotton lines. The line introduced at that time had higher total gossypol levels than the line that preceded it. Before the change, California oil mills had established a low-gossypol cottonseed meal market in poultry feeds. The high-gossypol cultivar increased meal gossypol levels and had a significant impact on the maximum level of the cottonseed meal that could be used in poultry feeds in that market. Lack of communication between cotton breeders and the oil mill industry regarding gossypol levels resulted in major market problems.

The oilseed crushing industry tries to work closely with plant breeders and other researchers to provide information to meet the needs of the industry and the consumers of their products. The same researchers can provide the National Cottonseed Products Association with information regarding new cultivars, cultural methods and pest control programs beneficial to the industry.

With the most significant cottonseed quality improvement, glandless cotton, implementation is probably what needs to be emphasized at this time rather than research. Our industry looks at glandless cotton with great expectations, in hopes that it will eventually provide quality protein for the food and non-ruminant animal markets. Of course, the National Cottonseed Products Association is primarily interested in glandless protein, but it must appreciate the necessity for high quality and quantity in lint yields. The industry is optimistic about the lint quality and yield, pest resistance and seed quality characteristics that cotton breeders are incorporating into their glandless materials.

In conclusion, the cottonseed products industry has its list of desires and hopes for seed quality and welcomes any forum to discuss these items with others who also expect so much from this versatile, renewable resource, the cotton plant.

Hopefully, we won't have another 60 to 80 years go by without some of the improvement in the qualities of the seed of this plant.

SUMMARY

Past and present studies show that cultivar, growing location, crop year and/or their interaction terms—cultivar x location, cultivar x crop year, location x crop year, and cultivar x location x crop year—are highly significant sources of variation associated with quality of cottonseed grown in the United States Cotton Belt. Breeding, agronomic and handling practices can be used to favorably alter the physical and chemical properties of cottonseeds to improve their processability into oil, feed and food products without affecting optimum fiber quality. Yet despite many years of published expressions of interest in improvement of cottonseed quality, there has not been a continuity of interest or research programs; there is little evidence that cottonseed quality has had an impact on improving cotton cultivars. And, we have now entered a new period of interest in cottonseed quality research, interest that has been heightened by the discovery of glandless cotton.