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Genetically Based Increases in Cotton Plant Lint Biosynthesis

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Abstract

Caloric analyses of the distribution of energy were carried out for 10 cotton (*Gossypium hirsutum* L.) cultivars, each planted in 1999, that had been widely grown at one time during a period from 1890 to 1998. For these analyses, plants were harvested, dried, weighed, and subsequently analyzed for protein, crude fat, lignin, cellulose, hemicellulose, nitrogen-free solubles, and ash according to standard AOAC methods. Analyses were performed on roots, stems with remaining leaves, burrs, seed, and lint. While the plants did not change markedly in photosynthetic capability, apportionment to lint production increased with the modern cultivars. Total caloric content per 100 g remained nearly constant, but the percentage by weight and in calories of vegetative tissues decreased from 59% for the earlier cultivars to 44% in modern cultivars. The change could be attributed to the genetically based increase of lint calories while those of the roots, stems, burrs, and seeds were decreased or remained relatively unchanged. The plant did not change markedly in photosynthetic capability, but its capability to apportion energy to lint production increased.

Introduction

Lint yields of cotton have increased consistently in the past century due to selections for lint production. Modern-day cotton plants make an earlier transition from vegetative to reproductive development during the time when maximal leaf mass and area are present (Wells and Meredith 1984a, 1984b, 1984c).

Crop studies have shown that cotton bolls from first-position squares (first potential boll on all fruiting branches) contribute 66-75% of total plant yield, while bolls from second-position squares contribute only 18-21% of total yield of modern cultivars planted conventionally (Jenkins et al. 1990a, 1990b). Thus, cotton breeding strategies that select for early maturity have favored more economical crop production because long season management costs are decreased.

In a previous study (Hedin et al. 1997), data on weights of lint, seed, burrs, stems, and branches were integrated with analyses of these plant parts for protein, fat, lignin, cellulose, hemicellulose, and nitrogen-free solubles to provide a caloric analysis of the distribution of energy in ripened cotton. For comparison and as background, caloric analyses on tissues from cotton plants at 40, 101, and 115 days after emergence were also carried out. About half of the caloric content in ripened cotton was constituted in lint and seed; the remainder was apportioned to vegetative tissues.

In this present study, 10 cultivars were planted in 1999. Each had been a widely grown cultivar at one time during a period from 1890 to 1998. As in our previous study (Hedin et al. 1997) data on weights of lint, seed, burrs, and stems were integrated with analyses of these plant parts for protein, fat, lignin, cellulose, hemicellulose, and nitrogen-free solubles to provide a caloric analysis of the distribution of energy in ripened cotton. The cultivars were compared for their ability to apportion their photosynthetic energy to biosynthesis of lint. This study also includes an analysis of roots.

Key Words: Caloric analysis, cotton plant, Gossypium hirsutum L., energy distribution, cotton lint, cellulose

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Materials and Methods

Plants were harvested at ripening and dissected to provide roots, stems with remaining leaves, burrs (carpel walls), and lint separated from seed. The sampling method consisted of selecting three adjacent plants from a 13-m plot, each replicated two times. Plant part weights were compared using ANOVA procedures (SAS Institute 1991). Duplicate analyses were performed on all samples for the determination of constituents.

Association of Official Analytical Chemists (AOAC) methods (Horwitz 1975) were used to determine total solids, crude fat, ash, protein, lignin, cellulose, hemicellulose, and nitrogen-free solubles, the sum of which accounted for all of the plant constituents. These tests resulted in the following analyses: total solids (moisture), 14.083; crude fat, 14.019; ash, 14.114; and total protein, 2.049 (% N x 6.25). AOAC methods were also used for analyses of acid detergent fiber, 973.18; and lignin (by loss on ignition), 973.18C (Helrich 1990). Neutral detergent fiber was determined by the methods of Van Soest and Wine (1967). From these procedures, lignin, cellulose, and hemicellulose were determined directly, and soluble cell wall contents (nitrogen-free solubles; NFS) were calculated by difference from 100%.

Total gossypol was not analyzed in this study because the previous work showed that it made only a minor contribution to the total plant energy (3.3-3.7 calories per 100 g). Caloric calculations were based on standard caloric values per gram: protein = 5.6, crude fat = 9.3, insoluble carbohydrates (lignin, hemicellulose, cellulose) = 4.3, soluble carbohydrates = 4.3 (Crampton and Harris 1969).

Results and Discussion

Table 1 provides agronomic data showing that modern cultivars (years 1941-1998) have an increasing efficiency for the production of reproductive tissue (mostly lint) while the percentage of vegetative tissue decreased by approximately the same degree. This supports the reports of Wells and Meredith (1984a, 1984b, 1984c).

Comparison of the plant-part dry weight averages of years 1-5 with years 6-10 showed that lint increased from 15.8 to 19.2%, respectively, while seed remained unchanged (28.8 and 28.6%, respectively). Stems decreased from 28.5 to 25.5%, respectively. In the same context, total vegetative tissues decreased from 55.4 to 52.1%, respectively, while lint plus seed increased from 44.6 to 47.9%, respectively. Overall, the cotton plant can be considered efficient for biosynthesis of reproductive tissues in that these constituted about 50% of the biomass at harvest.

Table 2 provides data on the distribution of the major groups of chemical constituents (protein, fat, lignin, hemicellulose, cellulose, nitrogen-free solubles, and ash) in ripened cotton. For added perspective, years 1-5 (1890-1938) and years 6-10 (1941-1998) were combined respectively and averaged. The most notable difference between the early and later years was the lower levels of nitrogen-free solubles of roots, stems, burrs, and seed (i.e., carbohydrates) for the later years. Perhaps these data indicate that the plant has become more efficient in biosynthesis of lint, although this was not evident in the relative amount of cellulose found in lint, but was a factor in yield of lint.

Table 3-4 provides a caloric analysis of energy distribution in four selected cotton cultivars that bridge the 108-year period. The first column gives the normalized plant part weights on a 100-g basis. With the two earlier cultivars (1890 and 1932), roots, stems, and burrs accounted for almost 59% of the total mass. With the two more recently utilized cultivars, roots, stems, and burrs accounted for 52.80 and 48.55% of the biomass. From 1890 to 1998, lint increased from 13.85 to 21.30% of the total biomass, but the relative biomass of seed increased by only 10.64% (from 27.25 to 30.15%). The relative biomass of stems decreased by 24% over the 108-year time period.

The total caloric content per 100 g remained nearly constant (442 to 453). The percent calories of vegetative tissues decreased from 54.1% for 'King' to 44.4% for

Table 1. Efficiency of obsolete and modern cultivars for production of seed and lint.

Cultivar / Year	Percent dry weight					Total	Total
	Roots	Stems	Burrs	Seed	Lint	veg.	lint & seed
	%	%	%	%	%	%	%
King, 1890	8.3	30.8	19.8	27.2	13.9	58.9	41.1
Lonestar, 1905	8.4	25.4	19.2	29.1	17.9	53.0	47.0
Dixie Triumph, 1914	8.7	23.0	19.5	31.6	17.2	51.2	48.8
Deltapine 11A, 1932	10.5	32.4	16.0	25.8	15.3	58.9	41.1
Stoneville 2B, 1938	8.6	30.7	15.8	30.3	14.6	55.1	44.9
Average, years 1-5	8.9	28.5	18.1	28.8	15.8	55.4	44.6
Deltapine 14A, 1941	7.5	27.1	19.4	27.7	18.3	54.0	46.0
Stoneville 2B, 1962	7.5	27.4	17.9	28.8	18.4	52.8	47.2
DES 422, 1982	7.8	23.7	20.8	28.1	19.6	52.3	47.7
Deltapine 5415, 1990	7.9	25.7	19.2	28.7	18.5	52.8	47.2
SureGrow 747, 1998	7.9	23.5	17.2	30.1	21.3	48.6	51.4
Average, years 6-10	7.7	25.5	18.9	28.6	19.2	52.1	47.9
LSD (0.05)	NS	5.9	NS	3.4	3.0	6.0	6.0

'SureGrow 747.' This decrease could be attributed mostly to decreasing stem calories and increasing lint calories while those of the roots, burrs, and seed were little changed.

On the other hand, even though boll lint calories increased by 53.9% (from 59.83 to 92.11) over the period, total cellulose calories increased only marginally (11.2%), further evidence that although the plant did not increase markedly in photosynthetic efficiency, its genetic capability to apportion energy changed markedly in a favorable direction.

Also notable were the changes of energy distribution in the boll tissues. Total burr calories decreased slightly (13.6%) and seed calories also increased slightly (12.5%), but lint calories increased by 50.4%, indicative of a successful breeding selection strategy. Presumably, lint biosynthesis might be increased further if seed biosynthesis could be decreased (Jenkins et al. 1990a, 1990b). The ratio of seed calories to lint calories decreased from 2.29 in the 1890 cultivar to 1.71 in the 1998 cultivar.

These calculations are made with the tacit assumption that energy released from the combustion of cotton tissues is a direct measure of the energy expended by the plant in producing the tissue. However, the energy released in combustion of these tissues is only the absolute minimum necessary to create them. The actual amount of energy needed to create each tissue likely depends upon the biochemical paths utilized. Tissue production likely involves many more calories per tissue than are released in combustion and may well differ among the tissue types sampled (Kirschner 1961).

Table 2. Distribution of chemical constituents in cotton plant parts over a 108-year period.

Constituent	Years[1]	Plant part				
		Roots	Stems	Burrs	Seed	Lint
		%	%	%	%	%
Protein	1-5	5.7	7.6	7.6	24.0	3.9
	6-10	5.0	7.2	8.1	22.7	3.8
Fat	1-5	0.7	0.3	1.1	15.9	0.0
	6-10	0.8	0.3	0.9	16.9	0.0
Lignin	1-5	16.7	19.0	21.3	11.2	2.0
	6-10	16.6	19.3	20.9	10.9	2.2
Hemicellulose	1-5	5.7	6.4	4.1	7.6	1.0
	6-10	7.5	7.3	6.1	9.5	1.1
Cellulose	1-5	52.5	49.5	45.6	25.1	91.8
	6-10	54.8	51.5	45.4	28.4	90.7
NFS	1-5	8.2	11.4	14.1	12.0	0.2
	6-10	4.6	10.0	11.5	8.0	0.7
Ash	1-5	10.5	5.8	7.2	4.2	1.1
	6-10	10.7	4.4	7.1	3.6	1.5

[1]Years 1-5: 1890-1938. Years 6-10: 1941-1998.

Table 3. Caloric analyses of energy distribution in ripened cotton plant tissue of selected cultivars.[1]

Cultivar/ Year	Tissue	Normalized plant weight (100 g)	Protein	Fat	Lignin	Cellulose	Hemicellulose	NFS	Ash
			%	%	%	%	%	%	%
King 1890	Roots	8.30	5.97	0.69	16.28	51.90	4.86	9.15	11.15
	Stems	30.85	9.10	0.48	20.44	47.94	3.75	11.28	7.01
	Burrs	19.75	7.15	1.09	22.80	45.82	3.05	14.25	5.84
	Seed	27.25	25.47	14.75	10.89	23.25	7.61	13.75	4.28
	Lint	13.85	3.89	0.00	2.49	89.48	0.93	2.35	1.05
DPL 11A 1932	Roots	10.50	5.85	0.74	15.07	52.28	4.64	12.09	9.33
	Stems	32.35	8.35	0.32	16.82	49.16	7.87	13.28	4.20
	Burrs	16.00	8.65	0.93	20.46	45.07	7.00	12.42	5.47
	Seed	25.80	23.90	16.67	10.73	24.85	7.97	11.90	3.98
	Lint	15.35	5.22	0.00	1.75	90.05	1.43	1.30	0.31
ST 213 1962	Roots	7.50	5.20	1.00	17.53	54.71	10.08	7.70	3.78
	Stems	27.40	5.57	0.32	18.10	54.94	9.00	9.07	3.00
	Burrs	17.90	7.17	1.03	19.46	45.98	5.11	15.05	6.20
	Seed	28.80	21.97	16.76	10.18	27.48	10.93	8.96	3.62
	Lint	18.40	2.82	0.00	1.74	93.38	0.41	0.57	1.08
SG 747 1998	Roots	7.85	5.19	0.68	15.41	55.86	7.65	5.10	10.11
	Stems	23.50	8.21	0.00	20.89	51.27	6.18	8.92	4.53
	Burrs	17.20	7.99	0.64	22.07	46.85	7.39	8.65	6.41
	Seed	30.15	24.87	16.67	11.93	27.05	7.99	7.23	4.26
	Lint	21.30	4.20	0.00	2.60	91.38	0.50	0.56	1.15

[1]Analyses by AOAC methods. LSD (0.05) values used to compare cultivars within a tissue: percent hemicellulose, 2.23 (burr); percent fat, 0.29; percent hemicellulose, 2.67 (seed); percent ash, 0.30; percent NFS, 3.49 (lint); percent ash, 0.59. All other comparisons were nonsignificant.

Table 4. Total calories of energy distribution in ripened cotton plant tissue of selected cultivars.[1]

Cultivar/ Year	Tissue	Protein	Fat	Lignin	Cellulose	Hemicellulose	NFS	Total (100 g/plant)
King/ 1890	Roots	2.78	0.53	5.81	18.52	1.73	11.15	32.63
	Stems	15.72	1.17	27.11	63.59	4.98	11.26	123.83
	Burr	7.91	2.00	19.36	38.92	2.59	12.10	82.88
	Seed	38.87	37.38	12.76	27.24	8.92	16.11	141.28
	Lint	3.01	0.00	1.48	53.37	0.55	1.40	59.83
DPL 11A 1932	Roots	3.44	0.72	6.80	23.60	2.09	5.46	42.11
	Stems	15.13	0.96	23.40	68.37	10.95	18.47	137.28
	Burr	7.75	1.38	14.08	31.01	4.82	8.55	67.59
	Seed	34.53	39.99	11.90	29.57	8.04	8.55	136.03
	Lint	4.49	0.00	1.16	59.48	0.94	0.86	66.93
ST 213 1962	Roots	2.18	0.42	5.65	17.64	3.25	2.48	31.62
	Stems	8.55	0.82	21.32	64.72	10.60	10.69	116.70
	Burr	7.19	1.72	14.98	35.39	3.93	11.58	74.79
	Seed	35.43	44.89	12.60	34.03	13.54	11.09	151.59
	Lint	2.91	0.00	1.38	73.88	0.32	0.45	78.94
SG 747 1998	Roots	2.28	0.50	5.20	18.86	2.58	1.72	31.14
	Stems	10.80	0.00	21.11	51.82	6.24	9.01	98.98
	Burr	7.69	1.02	16.32	34.65	5.47	6.41	71.55
	Seed	41.99	46.74	15.47	35.07	10.36	9.37	159.00
	Lint	5.02	0.00	2.38	83.73	0.47	0.51	92.11

[1]Calories per gram: protein, 5.6; fat, 9.3; soluble and insoluble carbohydrate, 4.3; cellulose and hemicellulose, 4.3 (estimate).

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