✗ Edible Cottonseed Flour by Air Classification of Glanded Seed: Cost Analysis[1]

K.M. DECOSSAS, R.S. KADAN, J.J. SPADARO[2], G.M. ZIEGLER, JR., and D.W. FREEMAN, Southern Regional Research Center[3], Agricultural Research Service, U.S. Department of Agriculture, PO Box 19687, New Orleans, LA 70179

ABSTRACT

A new, edible, 65%-protein cottonseed flour having the characteristics of flour produced from glandless cottonseed has been prepared from milled, hexane-extracted glanded cottonseed flakes by a simple, practical, economical air classification process. The product has physical and functional characteristics that make it attractive for use in food formulation and it meets the free gossypol standards of both the U.S. Food and Drug Administration and the Protein Advisory Group of the United Nations System. A process flowsheet and a material balance are given; capital costs, manufacturing costs, general expenses, profitability and selling prices are indicated for annual productions of up to 17.5 and 35 million lb of flour in hypothetical industrial-scale satellite plants having daily capacities of 25 and 50 tons of flour, respectively. It is estimated that fixed capital investment for a 25-ton/day plant would be $4.0 million, and for a 50-ton/day plant, $5.5 million. Production of edible flour from prime-quality cottonseed kernels would cost as little as 15.8 cents/lb and the selling price of flour, allowing for the value of coproducts, would be as low as 23.6, 18.9, and 16.5 cents/lb for payout periods of 2, 3 and 4 years, respectively. Selling price would be competitive with the price of soy protein concentrate over most of the production range studied.

INTRODUCTION

Two distinctly different approaches have emerged to eliminate or minimize the adverse effects of free gossypol in cottonseed protein (1). One approach is the development of glandless varieties of cottonseed that are essentially free of pigment glands. Although breeding efforts to develop glandless cottonseed have been substantial since 1959, less than 0.5% of U.S. cotton acreage was planted to glandless varieties as recently as 1976 (2). The acreage of glandless varieties in other cotton-producing countries of the world has also been insignificant. Whether plantings of glandless cotton will develop significantly during the 1980s depends on many circumstances, the primary one of which is the eventual world requirements for protein for people (3). Clark et al. (4) have reported on the economic evaluation of processing glandless cottonseed into flour. They estimated that, at a 25% discounted cash flow rate of return, the prices of flour, exclusive of sales costs, would be 36, 28 and 25 cents per lb for mills processing 100, 200, and 400 tons of seed/day, respectively, for 300 days/year.

The other approach to the gossypol problem is the development of processes that remove pigment glands without adversely affecting the protein fraction. Such improved processing technology has been long recognized as essential to increased use of cottonseed as a source of edible protein for supplemental feeding of the world's rapidly growing population (5). This approach is relevant to glanded seed, which comprises almost all of the world's annual cottonseed crop of 25.5 million metric tons.

As early as the 1960s, air classification was investigated as a means of pigment gland removal from solvent-extracted, glanded cottonseed (6-8). Although substantial reductions in free gossypol were obtained, the free gossypol content of the air-classified product exceeded the allowable limit of 0.045% for edible cottonseed flour (9), unless the product was subsequently extracted with polar solvents.

Recently, Kadan et al. (10,11) and Freeman et al. (12) invented and developed a simple, practical, economical air classification process for the production of a new edible flour from glanded cottonseed. The chemical composition and characteristics of this new flour, a protein concentrate, as well as its essentially bland flavor and light-cream color, are all conducive to its use in formulating foods with enhanced nutritive value and functional properties. Its protein content is about 65% on a moisture-free basis and its protein efficiency ratio compares favorably to that of casein. Protein solubility (in 0.02 N NaOH) is over 95% compared to about 50% for cottonseed flour from prepress-solvent extraction. The characteristics of the new flour are comparable to those of flour produced from glandless cottonseed.

This paper presents an economic evaluation of processing glanded cottonseed into flour by this process. It includes a cost analysis of two hypothetical industrial-scale plants, satellites of larger hypothetical cottonseed extraction plants, hereafter called parent plants, for producing 25 and 50 tons/day of the new, edible, 65%-protein flour by air classification of milled flour from hexane-extracted, glanded cottonseed flakes. The cost analysis is mostly based on data taken during simulated continuous processing in the pilot plant at the Southern Regional Research Center and at application test centers of equipment manufacturers. It includes fixed capital investment, manufacturing costs, general expenses, profitability, and selling prices when operating the hypothetical plants at various classification yields in Lubbock, Texas, and Greenwood, Mississippi, two major centers of the cottonseed processing industry.

PROCESS

The continuous process evaluated in this cost study (Figs. 1 and 2) is essentially the one invented by Kadan et al. (11). Whole and cracked meats from the parent plant, containing 8-10% moisture and 4% hulls by wt, are passed through a meats purifier where the hulls content is reduced to 2% by aspiration. The aspirated meats are then flaked to a thickness of 0.015 inch. The flakes are dried to 1.75% moisture on a continuous conveyor in a tunnel-type dryer by passing 82.2 C (180 F) air downward at a velocity of 300 ft/min through a 2-in. depth of flakes for 5.2 min. For the next 45 min, the dried flakes are extracted in a continuous vertical loop-type extractor to 2% residual lipids and 40-45% residual hexane, using an amount of 32.2 C (90 F) commercial hexane equal to 0.97 times the weight of dried flakes (13).

The defatted, solvent-damp flakes are desolventized in a vapor desolventizer-deodorizer system without addition of moisture or condensation of stripping steam. Ninety-eight to 99% of the hexane is removed at 71-76 C (160-170 F) by showering the flakes through superheated hexane vapor

[1]Presented at the AOCS Annual Meeting, 1981, New Orleans.

[2]Present address: 1455 Gardena Dr., New Orleans, LA 70122.

[3]One of the facilities of the Southern Region, Agricultural Research Service, U.S. Department of Agriculture.

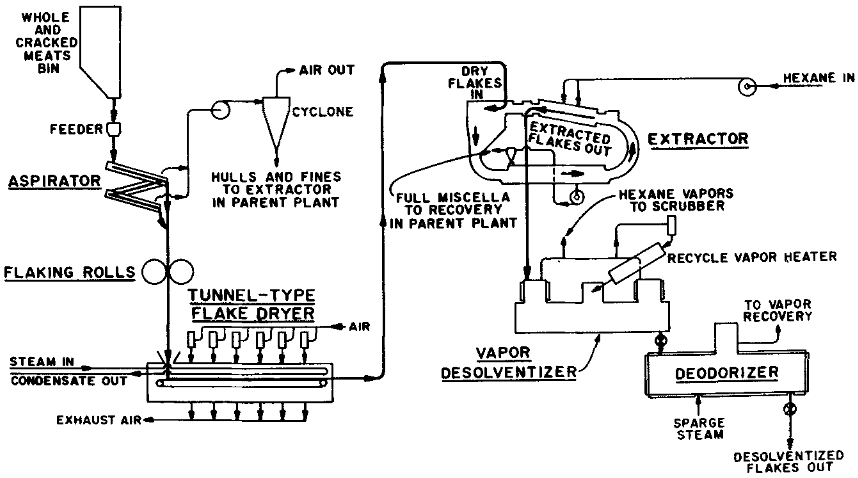

FIG. 1. Continuous air classification process, part I.

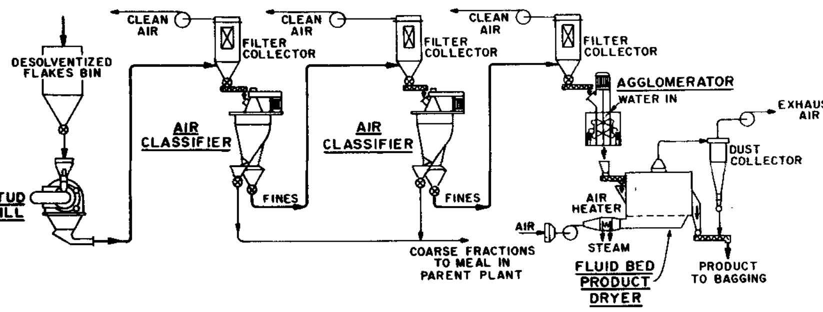

FIG. 2. Continuous air classification process, part II.

for 3-4 min. The flakes are then sparged with 150 psig steam for 30 min at 82.2 C (180 F) under a vacuum of 0.5 atm to remove essentially all of the remaining hexane. The desolventized flakes pass the "pop test" (14) which establishes their safety for further processing.

The flakes are then milled so that the particle size of 60% of the defatted flour produced is less than 25μ. The flour is air-classified in a spiral air classifier at a cut point of 45μ, yielding 53% fines and 47% coarse fraction. The fines are reclassified at a cut point of 25μ to yield 84% fines and 16% coarse fraction. The reclassified fines are ca. 44% by wt of the defatted flour and contain less than 0.045% free gossypol.

During agglomeration of the reclassified fines, water is injected and blended to produce granules containing 24.5% moisture. The granules are dried to 7.4% moisture by passing 176.7 C (300 F) air at a fluidization velocity of 120 ft/min upward through them for a maximum of 10 min, raising the temperature of the product no higher than 104.4 C (220 F). The edible flour product contains 65% protein by wt on a moisture-free and lipid-free basis and has the following screen analysis (U.S. Sieve Series): 12%>No. 20, 33%>No. 50, 37%>No. 60, 47%>No. 80, 55%>No. 100, and 67%> No. 140. It is a granulated, fluffy, dedusted, free-flowing flour that is readily mixable with other food ingredients.

Agglomeration and postagglomeration drying are optional, becoming necessary only if the air-classified flour has a fineness that makes it difficult to handle in a particular application.

MATERIAL BALANCE

The product yield in the material balance (Figs. 3 and 4) corresponds to a 44% yield of fines during two-stage air classification of defatted Texas High Plains cottonseed flour in commercial-size equipment. Other product yields of the cost study are based on two-stage air classification of defatted Mississippi cottonseed flour in a laboratory classifier. Those yields and their corresponding percentage yields of fines during classification are 261.0 lb, 45%; 224.8 lb, 39%; and 212.7 lb, 35%.

It is emphasized that the residual oil content of 1.8-2.0% after hexane extraction is on the basis of marc containing only 1.93% moisture and 2% hulls. It should not be compared to the usual residual oil content of less than 1% in the final meal without first converting to the same basis. Accordingly, the composite residual oil of all marc fractions from seed cleaned for flour production is the equivalent of only 1.3-1.4% in a final meal containing 7.5-9.5% moisture and 15% hulls. Thus, only ca. 4 lb less oil is produced from a ton of seed than in the case of solvent extraction to produce 41%-protein meal.

PLANTS

Each satellite plant includes all process equipment, piping, insulation, instrumentation, and controls required for producing flour from meats; service facilities; and a process building. Seed storage and meats preparation facilities are

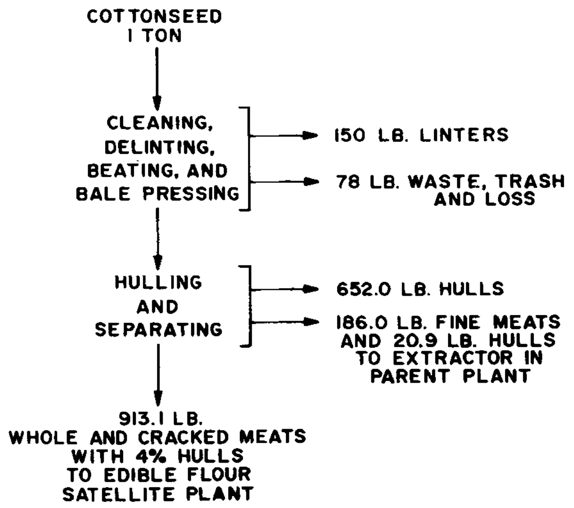

FIG. 3. Material balance for parent plant.

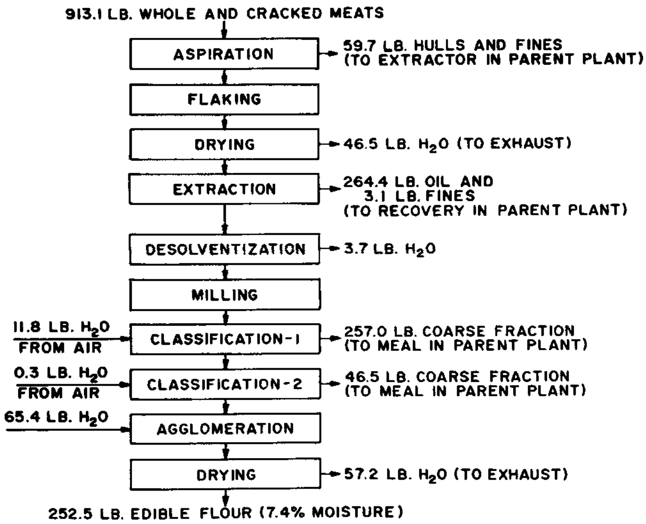

FIG. 4. Material balance for satellite plant.

available in the parent plants and the cost of their use is included in the cost of whole and cracked meats charged to the satellites.

The material of fabrication most generally used for surfaces in contact with the product prior to milling is carbon steel; and for the milling operation and thereafter carbon steel with food-grade epoxy coating is most generally used. Exceptions are the dryers and agglomerator for which 304 stainless steel is the standard.

FIXED CAPITAL INVESTMENT

Fixed capital investment (Table I) is estimated to be $4 million for the 25-ton/day plant and $5.5 million for the 50-ton/day plant. These estimates are based on the purchased costs of process equipment and service facilities quoted by equipment manufacturers. All costs in the study are applicable to the 3rd Quarter of 1980, when the Marshall and Swift equipment cost index for the process industries was 677.5 (1926 = 100) and the Austin Company building cost index was 292 (1967 = 100).

Continuous desolventization without either moisture addition or condensation of stripping steam is by far the costliest of the unit operations capital investment (Table II), especially in the case of the 25-ton/day plant for which it amounts to 42% of total fixed capital investment. Fixed capital investment for desolventization is proportionately higher in the 25-ton/day plant than in the 50-ton/day plant because equipment of essentially the same size is used in both. The minimal size, commercially available desolventization system used in both plants is oversized for the 25-ton/day plant but is less expensive than equipment especially sized for that plant because of the high cost of redesign and retooling that would be necessary. For only a 14% increase in capital investment, the minimal size desolventization system can be adapted for the 50-ton/day plant.

MANUFACTURING COSTS AND GENERAL EXPENSES

For the purpose of cost analysis, both size plants are assumed to be operated for 150, 200, 250, 300 and 350 days annually in the Lubbock, Texas, and the Greenwood, Mississippi, areas. Annual production corresponding to the various number of operating days for the 25- and 50-ton/day plants is shown in Table III.

Manufacturing cost, excluding the cost of meats, ranges from 8.1 to 15.3 cents/lb flour (Fig. 5). Of the four yields studied, costs for 44% classification yield from Texas seed are the lowest and those for the 35% classification yield from Mississippi seed are the highest. Costs for 39 and 45%

TABLE I

Edible Cottonseed Flour Plants—Fixed Capital Investment

	25-ton/day plant ($000)	50-ton/day plant ($000)
Direct costs (installed basis)		
Process equipment, piping, instrumentation and controls	2,323.2	3,142.9
Additional electrical	100.9	148.3
Outside lines	33.2	38.9
Steam boiler	55.0	77.0
Process building	77.0	118.4
Boiler house	5.3	6.6
Land and yard improvements	295.2	438.5
Subtotal	2,889.8	3,970.6
Indirect costs	1,107.6	1,521.9
Fixed capital investment	3,997.4	5,492.5

TABLE II

Edible Cottonseed Flour Plants—Fixed Capital Investment of the Unit Operations

	25-ton/day plant ($000)	50-ton/day plant ($000)
Unit operations		
Desolventization	1,705.6	1,950.2
Extraction	429.9	522.7
Postagglomeration drying	401.7	606.6
Flake drying	381.8	495.0
Air classification–1	244.3	488.6
Air classification–2	244.3	488.6
Milling	209.5	356.4
Bagging	160.8	262.7
Agglomeration	79.2	112.8
Flaking	77.2	145.8
Aspiration	63.1	63.1
All	3,997.4	5,492.5

TABLE III

Edible Cottonseed Flour Plants—Annual Production

	25-ton/day plant (mil lb)	50-ton/day plant (mil lb)
Operating days		
150	7.5	15
200	10	20
250	12.5	25
300	15	30
350	17.5	35

classification yields from Mississippi seed are in between, the costs for 45% yield being less than for 39% yield. Manufacturing costs of the various unit operations for processing Texas seed with 44% clsssification yield at both the lowest production level of the 25-ton/day plant (7,500,000 lb) and the highest production level of the 50-ton/day plant (35,000,000 lb) are given in Table IV.

In product applications in which air-classified flour can be used without subsequent agglomeration and drying, e.g., in textured cottonseed food products and protein isolates, the manufacturing cost given in Figure 5 would be reduced by an amount equal to the sum of the costs of the excluded operations. For example, it is estimated from the sum of the costs of agglomeration and postagglomeration drying in Table IV that manufacturing cost would be reduced 1.78 cents/lb flour when operating the 25-ton/day plant for 150 days/yr and 0.91 cents/lb when operating the 50-ton/day plant for 350 days/yr.

The cost of whole and cracked meats during the third quarter of 1980 was 38.76 cents/lb flour from Texas seed and 44.79 cents/lb flour from Mississippi seed. During that quarter, Mississippi seed sold for $25/ton more than Texas seed and during the entire 1979-80 season, it sold for an average $20/ton more. Meats cost is the largest single cost item, accounting for 58-76% of the sum of manufacturing cost and general expenses. It includes seed cost plus the cost of receiving, dumping, storing, retrieving from storage, cleaning, delinting and hulling, minus the value of the coproducts: fines, linters and hulls.

The cost for commercial hexane is based on a loss of 0.5

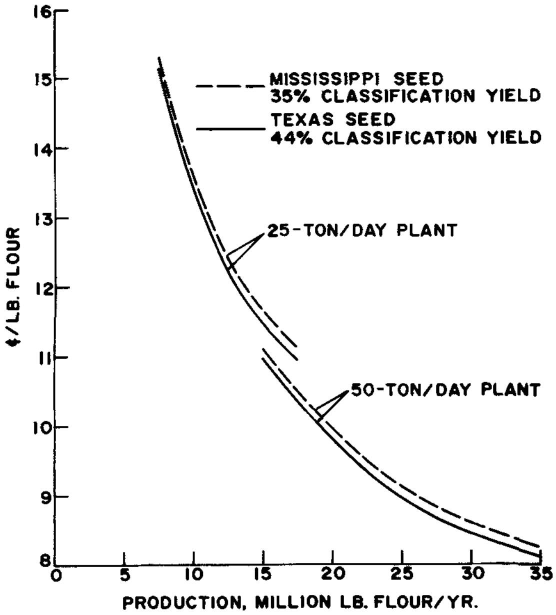

FIG. 5. Manufacturing cost (excluding cost of meats).

gal/ton of cottonseed processed and a bulk delivered price of $1.26/gal.

Operating labor cost is estimated at the average hourly earning rate of $7.26 reported for production workers on private, nonagricultural payrolls in the fats and oils industry in August 1980 (15). In addition, a night differential of 10% is allowed for second and third shift operations. Manpower includes two operators and a laborer for all three shifts plus an additional operator and a pallet loader for packaging during the daytime shift.

For the 25-ton/day plant, utilities cost totals 1.64-1.75 cents/lb flour (Table V), the lower value reflecting the lower energy rates in Texas. For the 50-ton/day plant, utilities cost is slightly lower, amounting to 1.52-1.60 cents/lb flour.

Other manufacturing costs include laboratory charges at 15% of operating labor cost; fixed charges, i.e., depreciation, property taxes and insurance totaling 8.7% of fixed capital investment; and plant overhead estimated at 60% of the sum of costs for operating labor, direct supervisory and clerical labor, maintenance and repairs.

The flour product, with a density of 17.2 lb/cu ft, is packaged in 25-lb quantities in 4-ply pinch-bottom bags priced at 50 cents each. The bags are made of 3 plies of 60-

TABLE IV

Edible Cottonseed Flour Plants—Manufacturing Costs of the Unit Operations (Texas seed, 44% classification yield

	25-ton/day plant, 150 days/yr (¢/lb flour)	50-ton/day plant, 350 days/yr (¢/lb flour)
Unit operations		
Desolventization	4.25	1.49
Bagging	2.81	2.38
Flake drying	1.67	1.00
Extraction	1.43	0.68
Postagglomeration drying	1.36	0.71
Classification—1	0.81	0.44
Classification—2	0.81	0.44
Milling	0.74	0.37
Flaking	0.45	0.26
Agglomeration	0.42	0.20
Aspiration	0.37	0.15
All	15.12	8.12

TABLE V

Edible Cottonseed Flour Plants—Utilities Cost (Production rate: 25 tons/day; 750 tons/month)

Utility	Unit cost of utility	Per lb of edible flour: Quantity	Per lb of edible flour: Cost
Steam (150 psig)	$4.00/M lb	2.63 lb	1.05¢
Process water	55¢/M gal	0.39 gal	0.02¢
Cooling water	10¢/M gal	0.54 gal	0.01¢
Electricity	4.222¢/kwhr (Lubbock, TX or 5.050¢/kwhr (Greenwood, MS)	0.132 kwhr	0.56¢ or 0.67¢
All utilities			1.64¢ or 1.75¢

lb kraft paper and a 3-ml inner polyethylene film, and they are provided with preapplied hot melt for field closing.

Manufacturing costs plus general expenses, excluding the cost of meats, range from 15.8 to 30.5 cents/lb flour (Fig. 6), about double the manufacturing costs of Figure 5. A major component of general expenses is financing cost, calculated at an interest rate of 11.5%, the average during the third quarter of 1980. At an interest rate of 21.5%, the peak rate this past year, the sum of manufacturing costs and general expenses is ca. 3-7 cents/lb higher than shown; from 3 cents/lb higher in the high production range to 7 cents/lb higher in the low production range.

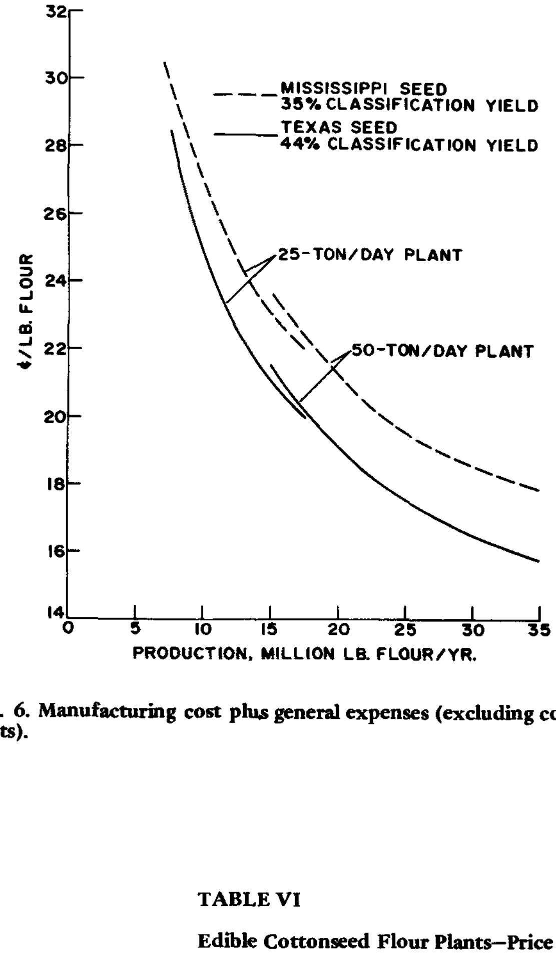

FIG. 6. Manufacturing cost plus general expenses (excluding cost of meats).

Other general expenses include administrative costs, distribution and marketing costs, and research and development costs, for which ca. 8% of total product cost is allowed, anticipating that certain economies will be realized because of the satellite's proximity to the parent plant where similar activities have already been established.

PROFITABILITY AND SELLING PRICE

The cost analysis shows that the price of flour at zero profit is as little as 11.0 cents/lb for Texas seed and 18.6 cents/lb for Mississippi seed (Table VI). This price includes the cost of meats as well as credit for the coproducts from the satellite plant shown in the material balance in Figure 4.

The value of the coproducts from the satellite, given in Table VII, is based on the following considerations: (a) the fines and hulls fraction, removed by aspiration from the whole and cracked meats and sent to the extractor in the parent plant, contains ca. 70 wt % fine meats. This coproduct, which comprises only 9.2 wt % of all coproducts from the satellite, is processed entirely into oil and meal and, accordingly, is given a value equivalent to that of meats, which was 10.7 cents/lb for Texas seed and 12.8 cents/lb for Mississippi seed during the third quarter of 1980.

(b) Fines in the 40 wt % oil/60 wt % hexane miscella from the extractor in the satellite are filtered from the miscella and sent to the extractor in the parent plant for processing into oil and meal. This coproduct consists almost entirely of fine meats from which no oil is claimed to have been extracted in the satellite.

(c) The 40 wt % oil/60 wt % hexane miscella from the extractor in the satellite, after fines removal, is sent to oil and solvent recovery in the parent plant where recovery is effected with heat available from meal desolventization. Since sufficient excess hot vapor from desolventization is already available in the parent plant for oil and solvent recovery of the miscella from the satellite, no cost is assessed flour production for such recovery and the oil in the miscella from the satellite is given the value of crude oil.

(d) The coarse fractions of flour from both air classifications are blended into the meal product from the parent plant without any adverse effect since cottonseed meal is used for ruminant feeding in Texas and Mississippi. No credit is claimed for the increase in value of the hulls added to the coarse fractions to make a 41%-protein meal.

TABLE VI

Edible Cottonseed Flour Plants—Price of Flour at Zero Profit

	Texas seed 44% Classification yield		Mississippi seed 45% Classification yield	
	25-ton/day plant,	50-ton/day plant,	25-ton/day plant,	50-ton/day plant,
	150 days/yr	350 days/yr	150 days/yr	350 days/yr
	(¢/lb)	(¢/lb)	(¢/lb)	(¢/lb)
Direct production costs	6.21	3.72	6.31	3.79
Fixed charges	4.64	1.37	4.64	1.37
Plant overhead costs	4.27	3.03	4.27	3.03
Total manufacturing costs	15.12	8.12	15.22	8.19
General expenses	13.31	7.65	14.03	8.37
Manufacturing costs and general expenses	28.43	15.77	29.25	16.56
+ Cost of meats	38.76	38.76	44.79	44.79
	67.19	54.53	74.04	61.35
− Value of coproducts	43.50	43.50	42.77	42.77
Price of flour at zero profit	23.69	11.03	31.27	18.58

TABLE VII

Edible Cottonseed Flour Plants—Value of Coproducts Per Ton of Cottonseed

Coproducts	Texas seed 44% Classification yield: Quantity (lb)[a]	Unit value	Value ($)	Mississippi seed 45% Classification yield: Quantity (lb)	Unit value	Value ($)
Fines and hulls from aspirator, to extractor in parent plant	59.7	10.7 ¢/lb	6.39	59.7	12.8 ¢/lb	7.64
Fines in miscella, to extractor in parent plant	3.1	10.7 ¢/lb	0.33	3.1	12.8 ¢/lb	0.40
Oil in miscella, to recovery in parent plant	264.4	27.7 ¢/lb	73.24	264.4	27.7 ¢/lb	73.24
Coarse fractions, 1st and 2nd classifications, to meal in parent plant	321.9[b]	$185.70/ton	29.89	313.5[b]	$193.60/ton	30.35
All coproducts	649.1		$109.85/ton (43.50 ¢/lb flour)	640.7		$111.63/ton (42.77 ¢/lb flour)

[a]From Fig. 4.
[b]Equivalent amount of coarse fractions containing 9.5% moisture.

The price of flour at zero profit for processing Mississippi seed is 7.0-7.5 cents/lb higher than for processing Texas seed over the entire production range studied (Fig. 7), primarily because of the higher price of cottonseed in Mississippi.

At a profit of $10/ton of seed processed, the selling price of edible cottonseed flour falls well below the 42-46 cents/lb selling price of soy protein concentrate (16), over the entire production range studied for both hypothetical plants using either Mississippi or Texas seed (Fig. 8).

For the 50-ton/day plant processing Texas seed with 44% classification yield, the selling prices of edible cottonseed flour for the 2, 3 and 4-yr payout periods are competitive with the price of soy protein concentrate over the entire production range studied for that plant (Fig. 9). (All

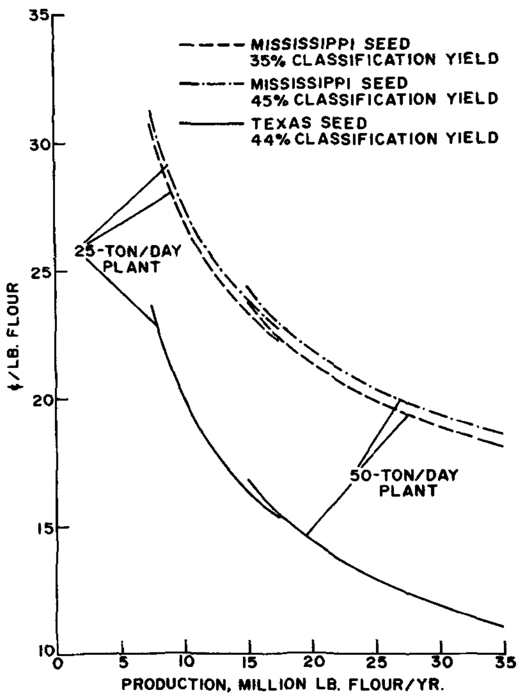

FIG. 7. Price of flour at zero profit.

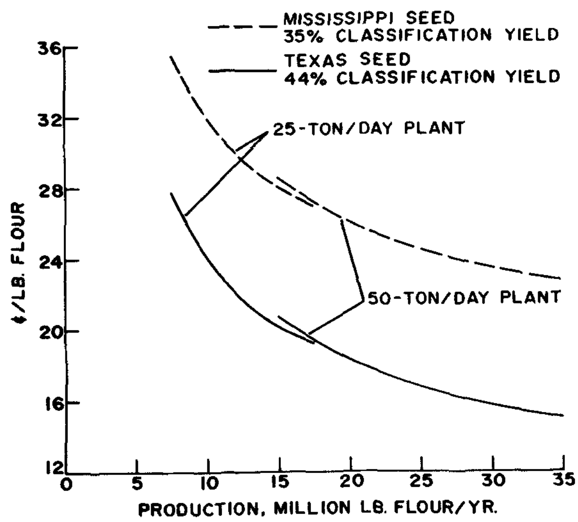

FIG. 8. Selling price of flour for profit of $10/ton of cottonseed processed.

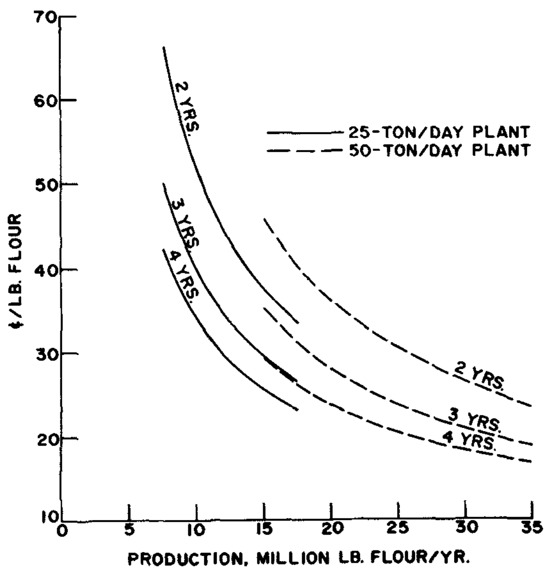

FIG. 9. Selling price of flour for various payout periods.

three curves for the 50-ton/day plant fall within or below the 42-46 cents/lb price range of soy protein concentrate).

For the 25-ton/day plant processing Texas seed with 44% classification yield, the selling prices of edible cottonseed flour for only the 4-yr payout period are competitive with the price of soy protein concentrate over the entire annual production range studied for that plant. Selling prices for the 2- and 3-yr payout periods are competitive over less of the production range.

Although selling prices of flour from Mississippi seed for the various payout periods and classification yields average 7.3 cents/lb higher than prices of flour from Texas seed, selling prices of flour from Mississippi seed from the 50-ton/day plant for the 2-, 3- and 4-yr payout periods are competitive with the price of soy protein concentrate over the entire production range studied for that plant except for 2-yr payout period and 150-day operations.

For the 25-ton/day plant, selling prices of flour from Mississippi seed for the 2-yr payout period are competitive only for 300- and 350-day operations. Selling prices remain competitive for operations down to 200 days only with a payout period of 4 years.

ENGINEERING PROSPECTUS

An engineering prospectus for the 25- and 50-ton/day cottonseed flour plants is available upon request from K.M. Decossas at the address given in the byline. It includes a flowsheet, material balances for various classification yields, a detailed equipment list with specifications and costs, a list of equipment suppliers, energy requirements, itemized manufacturing costs and general expenses for both size hypothetical plants operating for various lengths of season at two locations, and tables of profitability and selling prices of the edible flour product.

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Operating Variables in the Analysis of Tall Oil Acids by Capillary Gas Chromatography

G.M. DORRIS[1], **M. DOUEK** and **L.H. ALLEN**, Pulp and Paper Research Institute of Canada, 570 St. John's Blvd., Pointe Claire, Quebec, Canada H9R 3J9

ABSTRACT

Factors influencing the analysis of fatty and resin acid methyl esters by capillary gas chromatography have been investigated. Methods to calculate equivalent chain length (ECL) values and their limitations are first discussed. Retention data, expressed as equivalent chain lengths (ECL) were determined on SE-30, SP-2100 and Carbowax 20M columns. The medium length (20-30-m) polysiloxane columns, SE-30 and SP-2100, provided overall better resolution and shorter retention times than the more polar Carbowax 20M column of similar length. The temperature dependence of ECL values was investigated for all three columns in the range 180-210 C. Retention times and ECL values were more temperature-dependent for the Carbowax 20M than for the other two stationary phases. The effects of split ratio and method of injection on the precision and accuracy of the analysis were also examined. Using optimal conditions of analysis established in this paper, the difference between measured and actual weights of an internal standard added to two tall oil samples was determined to be less than 3%.

[1]Author to whom correspondence should be addressed.

INTRODUCTION

In the pulp and paper industry, millions of dollars are lost yearly because of problems arising from the resinous material in the wood (1-3). Wood resin is usually defined as the component of the wood which is insoluble in water but soluble in nonpolar, organic solvents such as ether, benzene or acetone (4). This material, which comprises about 1-5% by wt of the wood, is partially liberated during the pulping process (1) and can deposit on the surfaces of process equipment. If such deposits break away from their surfaces of attachment, they can contaminate the final product with dirt or cause sticking problems on the paper machines. Other materials used in the process, such as defoamers and sizing agents, can cause similar deposition problems; to determine the source of deposition, it is highly desirable to be able to analyze accurately the fatty and resin acids which are major components of wood resin.

Gas chromatography (GC) with packed columns has been extensively used for the separation of wood resin into