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INDUSTRIAL PROCESSING OF COTTON-SEED

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id. 78-[illegible]

Explanatory notes

Reference to dollars ($) are to United States dollars unless otherwise stated.

The following abbreviations are used in this publication:

AOCS	American Oil Chemists' Society
INCAP	Institute of Nutrition of Central America and Panama
LCP	Liquid cyclone process
NCPA	National Cottonseed Products Association
ORSTOM	Office de la recherche scientifique et technique d'outre-mer
PAG	FAO/WHO/UNICEF Protein Advisory Group
SRRC	Southern Regional Research Center
SRRL	Southern Regional Research Laboratory

The following technical abbreviations have been used:

c.i.f.	Cost, insurance, freight
f.o.b.	Free on board
pH	Hydrogen ion concentration

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A. The classification of cotton

The cotton tree belongs to the family of Malvaceae, Hibiscoeae tribe, genus Gossypium. Some botanists (Edlin, 1935) place the Hibiscoeae tribe in the family of Bombacaceae so as to bring all species producing fibres attached to a seed or a capsule together in one family.

Gossypium is by far the most important genus of the Hibisceae tribe.

Numerous woody or herbaceous perennial or annual varieties of cotton, from 0.5 m to 5 m high, can be found in the natural state.

All cultivated species are thought to be derived from a common ancestor in the Old World, which could be Gossypium herbaceum.

Cotton growing is a very ancient occupation: fragments of cotton cloth dating back to 3000 BC were found in Mohenjo Daro (Pakistan) and others, dating back to 2400 BC, in Peru (Lagière, 1966).

The cotton tree is normally a perennial plant, as were the varieties cultivated formerly, but the perennial varieties have gradually been replaced by annuals whose cultivation could be extended to more northern regions, where the perennials would not have survived the harsh winters.

Most of the cultivated species are annual arborescent shrubs, less than 1 m high.

The classification of Gossypium is an entangled and long debated subject. Taxonomy, however, is outside the scope of this study; suffice it to indicate that 15 wild lintless species are grouped into six sections, and that cultivated cotton trees can be divided into four main species - G. arboreum, G. herbaceum, G. hirsutum, and G. barbadense, each divided into many sub-species and varieties (Lagière, 1966).

G. arboreum and G. herbaceum

Gossypium arboreum and Gossypium herbaceum are species cultivated in the Old World. G. arboreum can be divided into six sub-species, and G. herbaceum into five, according to geographical origin.

G. arboreum

Sub-species indicum: consists of a perennial variety found in western India, Madagascar, and the United Republic of Tanzania, and an annual variety found in India.

Sub-species burmanicum: predominately perennial, but with annual varieties. Found in Burma, Bengal, Assam, Viet Nam, Malaysia, and the Indian archipelago.

Sub-species cernuum: annual, cultivated in Assam and Bengal.

Sub-species sinense: an annual early sub-species found in China, the Korean peninsula and Japan.

Sub-species bengalense: an annual found in northern India and Pakistan.

Sub-species sudanense: a perennial cultivated in Sudan and West Africa.

G. herbaceum

Sub-species persicum: annual, found nowadays in Iran, Afghanistan, western Pakistan, Soviet Central Asia, Iraq, Syrian Arab Republic, Turkey, Greece and the Mediterranean islands.

Sub-species kuljianum: annual, suited to the short summers and cold winters of Central Asia (USSR, Sinkiang) where it is found.

Sub-species whightianum: an annual from western India.

Sub-species acerifolium: perennial from Africa (Sudanese region, Ethiopia, oases of Egypt and the Libyan Arab Jamahiriya) and the Arab countries.

Sub-species africanum: a perennial found in South Africa.

The linters remaining on G. arboreum and G. herbaceum after ginning are not very thick: they account for between 3 and 5 per cent of total seed weight, and sometimes as little as 2 per cent; so the seeds look almost bare.

Gossypium hirsutum

G. hirsutum originates from the New World. It includes one wild sub-species from Hawaii, G. tomentosum, and seven cultivated sub-species (marie-galante, punctatum, palmeri, yucatanense, morrillii, richmondi, latifolium) which have spread throughout the entire world from their origin (southern Mexico and Guatemala). The three main sub-species are marie-galante, punctatum and latifolium:

Sub-species marie-galante: a perennial shrub which was the basic stock used for the Antilles cultivations. It was later brought into north and eastern Brazil, Ecuador, the Guianas and West Africa (Ghana, Togo, Ivory Coast and elsewhere).

Sub-species punctatum: also a perennial, widely distributed throughout the tropical and semi-tropical regions: Central America, Antilles, Florida, West Africa, Egypt, Ethiopia, India, Philippines, Australia. Annual varieties have been developed in West Africa.

Sub-species latifolium: an annual from which the "upland" variety was developed in the southern United States (Carolina and Georgia).

G. hirsutum is the species that has benefited most from selection work, mainly in the United States, to improve the yield and quality of cotton fibre under local conditions (climate, soil, etc.). The result has been many varieties, derived either from the development of former varieties or from hybridization or crossing. The work began in the early nineteenth century and is still going on.

When the United States was a British territory, two varieties of cotton were used in the south. One, "sea island" or "lowland cotton", originated in the Antilles; its seed, which retains no linters after ginning, is black or brownish-red,1/ giving rise to the name "black seed". The other variety, which originated in Mexico, retains thick grey or white linters after ginning, and is called "upland cotton". "Upland cotton", which gives a higher yield, superseded "lowland" and has given rise, as a result of selection work, especially since 1850, to many varieties. The complete classification cannot be given here, but the more commonly known varieties are derived from the following 16: fox, empire, rowden, mebane triumph, western mebane, lankart, paymaster, macha, hibred, delfos, extra-long-staple upland, miscellaneous upland, delta pine, stoneville, coker 100, and acala (Lagière, 1966). The last five types are particularly important; most of the 16 (some of which are divided into sub-types) are represented by several varieties.

1/ The bulk of the cotton-seed is usually black, but may vary in shade from brownish-red to jet-black.

Some G. hirsutum varieties are cultivated not in the United States, but in other places to which they have been acclimatized: Brazil, USSR, Africa (Chad, Nigeria, Uganda), China, India, and elsewhere.

G. barbadense

Gossypium barbadense, which also comes from America, has two sub-species:

G. brasiliense: in north-eastern Brazil, Central America, the Antilles, Africa and India.

G. darwinii: found in the Galapagos islands, is quite rare elsewhere, although it is related to important cultivated varieties.

These two sub-species, which were originally perennials, gradually became annuals as they developed in Africa (along the Gulf of Guinea - Nigeria, Togo and Benin - and later in Egypt), America (in South Carolina, for example, where they were the basis for the sea island varieties) and Peru.

G. barbadense has medium, long or extra-long staple.

G. barbadense varieties with medium staple (ashmouni, giza 66), long staple (giza 47, dendera, giza 67) or extra-long staple (menoufi, giza 45 or 68) are grown in Egypt. The Soviet long-staple varieties are also G. barbadense, derived from Egyptian varieties.

B. Cotton varieties cultivated and cultivation areas in the main producing countries

United States

Cotton growing started in the states bordering on the Atlantic (Virginia, the Carolinas, Georgia, Louisiana) and gradually spread from the end of the eighteenth century, to the whole cotton belt. Between the two World Wars, and particularly after the Second, improvements in irrigation techniques enabled it to develop westwards.

The varieties grown are derived from upland varieties of G. hirsutum.

The cotton-growing area can be divided into four main regions:

The South-East (North Carolina, South Carolina, Georgia, Alabama, Florida, Virginia), where moderate rainfalls impose a need for additional irrigation, and the soil is poor. The fields used are often small.

The central South, also called "the delta", includes all the states bordering on the Mississippi and its affluents (Missouri, Arkansas, Tennessee, Louisiana, Mississippi, Illinois and Kentucky). Although rainfall is high, irrigation is used to improve yields. Soils are light, deep and rich.

The South-West, which covers all the jagged high plateaux of the South (Texas, Oklahoma). Because of scanty rainfall, varieties must be chosen that mature early and are drought-resistant. Soils are fine, sandy, and moderately rich.

The West (California, Arizona, New Mexico, Nevada). This is a dry region with deep, rich soils which give high yields with the help of irrigation.

Soviet Union

Cotton growing is mainly concentrated in the Republics of Central Asia (Uzbekistan, Tadjikistan, Turkmenistan, etc.), but cotton is also grown in Transcaucasia (Azerbaijan, Armenia). The climate is dry and continental; so irrigation is essential. The soil, which is generally deep and rich, is sometimes too salty.

The first species cultivated was G. herbaceum, which still accounts for much of the production. Upland varieties were introduced around 1880, and G. barbadense more recently.

China

Five production areas can be distinguished:

The Huanghe basin: the main production area which accounts for more than 50 per cent of the cultivated area. Rainfall is scanty and badly distributed.

The Yang-Tze basin: rich alluvial plains with moderate rainfall.

The North-West area (Xinjiang): irrigation is necessary because of insufficient rainfall.

The North-East area (the Laokai basin).

The Southern area, with abundant rainfall.

The traditional species are G. herbaceum and G. arboreum. The latter was imported from India more than a thousand years ago. Uplands were introduced in about 1850 but did not develop until after about 1930.

India

Cotton has always been cultivated in India. The producing areas and the main species are as follows:

Northern area	G. hirsutum, G. arboreum
Northern Central area	G. arboreum
Southern Central area	G. arboreum, G. herbaceum, G. hirsutum
Southern area	G. hirsutum, G. arboreum
Western area	G. herbaceum
Eastern area	G. arboreum

Some G. barbadense can be found along the coasts (sea island, andrews).

The local varieties, which are called desi, are mainly G. arboreum. About 60 per cent of the cotton area is planted with G. arboreum and G. herbaceum, and 40 per cent with G. hirsutum. G. barbadense is planted in negligible quantities.

Pakistan

The varieties grown in Pakistan are similar to those grown in India, but there is a greater proportion of G. hirsutum, derived from upland.

Brazil

There are two clearly separated production areas in Brazil: the South (São Paulo, Parana and Minas Gerais states) which provides about two-thirds of the harvest, with upland varieties, and the North-East where the main varieties are either perennial Moco[2/] or herbaceous annual varieties.[3/]

Egypt

The provinces of lower Egypt (Nile delta) are planted with extra-long-staple varieties. Long- and medium-staple varieties are grown in middle Egypt, and in upper Egypt only medium-staple varieties are grown.

All the varieties belong to the species G. barbadense, which produces cotton that is well-known for its length, fineness and hard wearing qualities.

2/ Derived from a complex mixture of genes from G. hirsutum (marie-galante), G. hirsutum latifolium, and G. barbadense brasiliense.

3/ These are improvements of former varieties introduced from Africa or the United States.

Turkey

The cotton areas are as follows, in order of decreasing importance:

Tchoukouroua (Adana), in north-east Cyprus

Egea (Izmir)

Antalya, in north-west of Cyprus.

G. herbaceum (also called yerli), which was grown in Turkey for more than a thousand years, has now been almost completely replaced by upland. Some G. barbadense may also be found.

Mexico

Most of the Mexican varieties are uplands brought from the nearby United States cotton belt.

Sudan

As in Egypt, most of the cotton grown in the Sudan is G. barbadense, although some upland varieties are grown without irrigation in the south.

Peru

The main variety grown in Peru is G. barbadense.

C. The physiology of the cotton plant

Five phases can be distinguished during the life of the cotton plant. (Legière, 1966).

The sprouting phase

The sprouting phase, from germination to the time the cotyledons unfold, lasts for six to 30 days, and requires both moisture and heat. Water must reach the embryo for the biochemical germination process to start. Even when water is present, germination does not start at temperatures below 14° C; it is slow between 14° and 25° C, rapid and normal at 30° C, and hardly occurs above 40° C.

The best conditions are therefore a soil temperature of 25°-30° C and a soil humidity of 90 per cent saturation.

The seedling phase

The seedling phase, from the time the cotyledons unfold until the plant has three or four leaves, lasts for 20-35 days. Exchanges with the environment and cell metabolism are active. They depend upon the soil and atmospheric humidity, temperature, light, and the physical and chemical properties of the soil.

The best conditions during this phase are a soil temperature above 20° C, an air temperature of 25°-30° C, and moist (not saturated) aerated soil.

The seedling phase is of critical importance for the future development of the plant; any lack of soil nitrogen will make itself particularly felt.

The pre-flowering phase

The pre-flowering phase, from when the seedling has three or four leaves until flowering begins, lasts for 30-35 days during which the seedling grows quickly. The first flower bud usually appears 35-45 days after sprouting. Subsequent development is so fast that a new bud is formed every three days.

Moisture, air and warmth are of course important, but the most important factor during this phase is soil fertility. The more fruit-bearing branches there are, and the longer they are, the more numerous will be the flowers. The number of flowers is therefore proportional to the size of the plant.

The flowering phase

The flowering phase lasts for 50-70 days. Each flower opens 20-25 days after the bud forms. The rate of flowering is accelerated by a warmer and drier climate. The growth of the cotton plant slows down from the beginning of the flowering stage.

Pollenization of the cotton flower usually occurs on the day the flower opens. The ovary has two to six carpels, each of which bears eight to 12 ovules.

The capsule maturation phase

The capsule maturation phase lasts for 50-80 days. After fertilization, the ovary enlarges rapidly. The fruit is a mottled greenish ovoid, elongated or round capsule 2-5 cm long. The surface shows many glands. Each capsule contains 18-45 seeds, six to nine to a cell. The seeds are rather large: 7-12 mm long and 4-6 mm across. They are ovoid or pearshaped. Depending on the year and variety, 100 seeds weigh between 7 and 17 g. The weight per 100 seeds is called the seed index and is used to indicate the seed size. Cultivated cotton-seeds are covered with long fibres called lint. G. hirsutum seeds are also coated with a thick down of shorter fibres called linters or fuzz. G. arboreum and G. herbaceum are less downy. G. barbadense does not have a secondary cover and after ginning - the separation of lint from seed - appears completely naked. The linters can be white, grey, green or brown. The seed hull is black or brownish, hence the name "black seed" given to the G. barbadense ginned seed.

During capsule maturation, water and light are most important. For the first 21 days, the ground must be sufficiently moist for the nutritive substances to migrate, but must not be saturated. After the 21st day, sunshine is needed to speed up maturation and bring about dehiscence (the bursting of the capsule along the carpel suture lines). The cotton fibres then fluff out and dry gradually with the seed.

The temperature also plays a part: in general, the higher the temperature, the more lint there will be in the capsules; the shorter and coarser the lint, the lighter will be the seed, the lower its oil content and the higher its protein content. However, the effects do not always occur exactly in this way.

Once the first capsules have opened, more flowers may open, thus starting a second flowering phase.

D. Cotton cultivation

The method of cotton growing depends on the type of farming (extensive or intensive culture, small plots or large farms, etc.) and the stage of economic development of the grower countries. In the United States, for example, cultivation is highly mechanized, while in Africa manual labour is the only means. Elsewhere, the situation is an intermediate one: the main work is done by machines and the rest by hand.

Crop rotation

The cotton tree needs good soil. With a tap-root that is 0.60-3 m long, it requires a deep and porous soil. Since standing water is liable to cause disease, the soil must be well drained. It must also be fertile, since the plant develops bushy vegetation within a few months. Cotton exhausts soil faster than many other crops.

If the soil is very rich and fertilizers are used, crop rotation can be avoided, as, for example, in some areas of the United States. Crop rotation is often resorted to, however, not only to maintain or increase fertility, but also to counter diseases and weeds. In tropical areas, it is also a way to combat leaching and erosion of the soil: the cotton plant, which covers the soil for only part of the year, does not perform this function.

The choice of rotation system is a difficult one that involves many technical and economic factors. One frequently used system is a three-year rotation of cotton with one year of leguminous plants and one year of cereals.

Climatic conditions

In the best conditions, the whole cotton tree cycle lasts 166 days; in less favourable conditions, it may last 205 days. Since cotton is sensitive to cold, the temperature must not drop too low during the five to seven months of its cultivation, and must never fall below 5° C. This means that cotton is geographically limited to tropical of subtropical regions, and early varieties must be selected for countries with cold winters (the Soviet Union, for example).

Fertilization

Nitrogen is the most important element for the cotton tree, and the soil is often lacking in nitrogen. The amount applied in the form of fertilizers[4/] varies from 40 to 200 kg/ha.

Phosphorus deficiency is the second most common problem after nitrogen deficiency. Phosphated dung provides some 20-80 kg of P_2O_5 per ha.

When potassium is needed, 20-80 kg/ha are applied.

4/ Nitrogen fertilisers include urea and ammonia.

Irrigation

Irrigation is dispensed with where the climate permits. This method of cultivation is called "rain growth".

When the climate is dry and hot, irrigation is necessary to provide all the water needed or supplement inadequate supplies.

Generally speaking, irrigated cultivation produces higher and more regular yields, and better-quality staple.

Harvesting

Seed cotton[5/] is harvested by machine or by hand in two, three or even four operations.

Manual harvesting, formerly the universal method, is still used in countries where labour is plentiful and cheap, or on small family plantations.

Mechanical harvesting, which is being used more and more, has been developed for economic reasons: efforts to reduce costs, or a shortage of labour. The seeds thus harvested are mingled with impurities (capsules, leaves, small branches), however, which must be removed afterwards, by processes that reduce the fibre strength. Unripe capsules may also be picked, which entails economic losses. Equipment manufacturers have tried to overcome these drawbacks, but without complete success. Before the machines start work, defoliants are spread so as to ensure that the leaves do not mix - or rather mix less - with the seed cotton.

There are two types of mechanical harvester:

Strippers, fitted with rollers, brushes or rakes which literally comb the plant and tear off the capsules (ripe or unripe) with a high proportion of waste.

Pickers, on the front of which are mounted pins set in vertically mounted drums. As the drums rotate, they turn the pins, which also rotate. The pins enter the cotton plant, and catch on the cotton of the open capsules. To make the fibres catch better, the pins are moistened by a humidifier. Inside the machine, the fibres are taken off from the pins by a carder. In some pickers, the pins are replaced by a suction system or an electrical system that attracts the fibres on to electrically charged strips or fingers.

5/ "Seed cotton" is the seed complete with lint, as distinct from cotton-seed, which is the seed from which the lint has been removed by ginning.

The pickers' output is about half that of the strippers but the seed cotton they harvest contains fewer impurities.

Cotton pests

There are many cotton pests, falling into two categories: micro-organisms (fungi, bacteria, viruses), which are responsible for many cotton plant diseases; and parasitic insects.

In the humid tropical areas, diseases cause a loss of approximately 15 to 25 per cent.[6] The percentage loss due to insects is not known, but it is certainly high.

The means used to counter pests include pesticides, the introduction of entomophages or insect parasites, the destruction of waste and the burning of cotton plants after the harvest, seed disinfection, and crop rotation with a gap in cotton growing of at least a year.

E. World cultivated areas, production and yields

As the economic value of the staple for textile purposes represents 80 to 90 per cent of the value of cotton products, compared with 10-20 per cent for the seed, it is not surprising that international production statistics are expressed in terms of lint weights.

The following table, however, shows how the weight of a whole dehydrated plant is distributed on average.

Table 1. Weight in grams and as a percentage of different parts of mature cotton plants

Plant part	Weight (grams)	Percentage
Roots	14.55	8.80
Stems	38.26	23.15
Leaves	33.48	20.35
Capsules	23.49	14.21
Seeds	38.07	23.03
Lints	17.45	10.56
	165.30	100.00

6/ Even in the United States, losses were still estimated to be 16 per cent of production in about 1960.

It can be seen that the weight ratio of lint to seed + lint is 31.4 per cent. An easy way of converting a lint yield into a total seed yield is to multiply the lint yield by three; the yield of seed alone can likewise be obtained by multiplying the lint yeild by two. The results are only approximate, however, since the lint percentage in the whole seed depends on the variety and many other factors. The ratio is usually from 30 to 43 per cent, with the following ranges:

Variety	Percentage
G. arboreum and *G. herbaceum*	30-33
G. barbadense	30-34
G. hirsutum	33-39 (40-42 for some varieties)

Tables 2, 3 and 4 show the movement over the last few years of cultivated acreages, yields and production in the world. It can be seen that in 1976/77 (provisional figures), lint yields in the main producer countries were as follows:

Country	Yield (kg/ha)
Brasil	232
China	479
Egypt	739
India	143.5
Mexico	872
Pakistan	205
Peru	633
Sudan	349
Turkey	776
United States	521
USSR	897

Source: Quarterly bulletin of the International Cotton Advisory Committee, World Cotton Statistics, October 1977, vol.31, Nos. 2 and 3.

Converted into thousand tons of lint, 1976/77 production (provisional figures) of the main producer countries are therefore:

Country	Thousand tons
Brazil	499
China	2 363
Egypt	396
India	1 084
Mexico	221
Pakistan	390
Peru	67
Sudan	152
Turkey	470
United States	2 298
USSR	2 645
Total for the 11 countries	10 585
World total	12 505

Source: Ibid.

The eleven countries considered thus accounted for 84.6 per cent of world production in 1976/77.

F. Description and composition of cotton-seed

The complete cotton-seed comprises the lint and the seed proper. Unless otherwise stated, the word "seed" will henceforth be used in this study to mean the seed cleaned of lint.

The seed thus defined has three main components:

The linters (also called "fuzz") made of all the short-fibres still attached to the seed after ginning,

The hull or spermoderm,

The kernel or embryo.

The proportions of the three components depend upon the varieties, the growing conditions, the climate, the moisture content of the seed, the seed maturity, the storage conditions, the processes undergone, and so on. We have

Table 2. Areas planted under cotton, and lint yields

COUNTRY	ACREAGE				YIELD			
	1973/74	1974/75	1975/76	1976/77 prel.	1973/74	1974/75	1975/76	1976/77 prel.
	1,000 acres a/				Pounds per acre b/			
NORTH AMERICA								
EL SALVADOR	230	230	180	200	717	717	713	717
GUATEMALA	256	275	200	235	1,037	863	1,099	1,070
HONDURAS	23	20	11	25	514	540	620	405
MEXICO	1,040	1,402	581	627	[illegible]	700	749	770
NICARAGUA.	461	443	356	[illegible]	[illegible]	[illegible]	670	615
UNITED STATES. . .	11,970	12,567	8,796	10,[illegible]	520	441	453	465
OTHERS	24	22	19	23	-	-	-	-
TOTAL	13,[illegible]	14,[illegible]	10,147	12,[illegible]	551	[illegible]	[illegible]	501
SOUTH AMERICA								
ARGENTINA	1,171	1,240	1,082	1,[illegible]	230	303	[illegible]	319
BOLIVIA c/	125	170	75	[illegible]	[illegible]	[illegible]	510	470
BRAZIL	5,700	5,500	4,700	5,[illegible]	207	212	186	207
COLOMBIA	633	777	622	[illegible]	[illegible]	[illegible]	430	329
ECUADOR	57	105	81	66	219	[illegible]	268	219
PARAGUAY	230	250	262	340	229	229	274	221
PERU	362	360	230	284	566	[illegible]	[illegible]	565
VENEZUELA	200	310	151	125	[illegible]	[illegible]	333	325
OTHERS	1	1	1	2	-	-	-	-
TOTAL	8,[illegible]	8,511	7,153	8,[illegible]	251	[illegible]	244	251
WESTERN EUROPE								
GREECE	368	371	333	373	[illegible]	752	851	694
ITALY	8	12	12	10	[illegible]	172	199	230
SPAIN	[illegible]	249	183	126	420	510	523	474
YUGOSLAVIA	[illegible]	[illegible]	15	15	[illegible]	[illegible]	[illegible]	319
TOTAL	[illegible]	[illegible]	543	[illegible]	[illegible]	[illegible]	717	593
EASTERN EUROPE								
ALBANIA	56	56	56	56	251	251	261	261
BULGARIA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	273
USSR c/	6,775	7,116	7,210	7,[illegible]	783	873	772	[illegible]

a/ 1 acre = 0.4047 ha.

b/ 1 pound = 0.454 kg.

c/ Revised series.

/...

Table 2 (Cont'd)

COUNTRY	ACREAGE 1973/74	ACREAGE 1974/75	ACREAGE 1975/76	ACREAGE 1976/77 Prel.	YIELD 1973/74	YIELD 1974/75	YIELD 1975/76	YIELD 1976/77 Prel.
	1,000 acres a/				Pounds per acre b/			
ASIA AND OCEANIA								
AFGHANISTAN c/ .	105	275	300	320	300	340	361	373
AUSTRALIA . . .	76	83	73	79	800	875	762	967
BURMA	400	300	400	500	78	56	60	72
CHINA, PEOP.REP. .	12,000	12,000	12,000	12,100	466	450	420	427
INDIA	16,715	18,830	18,435	18,700	141	151	130	129
IRAN	895	912	717	730	514	574	427	450
IRAQ	150	150	130	150	223	223	202	223
ISRAEL	70	95	96	101	1,060	1,157	1,130	1,103
KOREA, REP. . . .	33	26	25	25	300	290	260	207
PAKISTAN	4,559	5,019	4,574	4,094	310	279	240	303
SYRIA	495	509	514	407	606	630	670	630
THAILAND	105	140	150	170	341	307	319	337
TURKEY	1,674	2,070	1,656	1,500	676	637	640	692
YEMEN, P.D.R.. . .	30	30	30	30	296	336	230	319
OTHERS	122	130	125	120	-	-	-	-
TOTAL	39,477	40,309	39,225	39,720	303	303	292	300
AFRICA								
ANGOLA	203	200	150	150	276	309	191	191
BENIN	131	120	100	110	203	227	215	230
CAMEROON,U.R.. . .	151	150	101	190	152	210	230	210
CENTRAL AFR.EMP. .	300	336	334	320	110	115	79	101
CHAD	666	672	831	700	146	170	172	150
EGYPT.	1,641	1,507	1,307	1,306	600	640	603	659
IVORY COAST. . . .	144	146	160	173	300	283	341	304
KENYA	130	170	170	200	92	60	60	72
MADAGASCAR	33	40	40	45	775	774	661	690
MALAWI	110	100	100	100	120	110	130	120
MALI	172	171	216	200	246	256	300	306
MOROCCO.	40	35	43	30	331	328	202	230
MOZAMBIQUE	700	700	600	600	130	129	100	100
NIGER	32	33	41	46	127	166	224	150
NIGERIA.	1,300	1,235	1,300	1,400	56	93	97	102
SENEGAL.	71	90	97	100	371	306	202	300
SOUTH AFRICA . . .	250	250	220	250	364	411	272	302
SUDAN	1,223	1,223	1,013	1,075	436	307	212	311
TANZANIA	700	700	500	700	206	225	166	222
UGANDA	1,704	1,246	1,475	1,000	62	56	37	40
UPPER VOLTA. . . .	166	152	160	230	132	164	236	289
ZAIRE	400	300	266	300	101	92	72	75
OTHERS	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-
TOTAL	10,834	10,200	9,563	10,025	153	206	179	203
WORLD TOTAL . . .	80,323	82,341	74,304	78,514	376	375	360	361
SOCIALIST COUNTRIES	18,980	19,330	19,475	19,600	577	590	590	586
ELSEWHERE.	61,333	63,010	54,999	58,914	314	309	276	300

Table 3. Production of cotton staple

(thousand bales)

COUNTRY	1968/69	1969/70	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76	1976/prel.
	YEAR BEGINNING AUGUST 1st								
NORTH AMERICA									
BR. W. INDIES	1	1	-	-	1	1	2	1	1
COSTA RICA	17	10	8	-	1	3	2	2	6
CUBA	5	5	5	5	5	5	5	5	5
EL SALVADOR	203	210	252	315	323	345	345	275	300
GUATEMALA	300	260	265	375	430	555	405	460	530
HONDURAS	35	15	9	11	20	25	23	14	25
MEXICO	2,450	1,750	1,440	1,715	1,780	1,500	2,230	910	1,020
NICARAGUA	420	310	360	400	485	660	560	505	515
UNITED STATES a/ b/	11,030	9,950	10,269	10.270	13,890	13,300	11,525	8,500	10,600
OTHERS	3	3	3	3	3	3	3	2	2
TOTAL	14,544	12,514	12,609	13,174	16,938	16,397	15,180	10,674	13,004
SOUTH AMERICA									
ARGENTINA	520	670	390	400	[illegible]	585	790	615	800
BOLIVIA	20	17	45	70	115	115	100	80	90
BRAZIL c/	3,385	2,675	2,700	3,135	3,000	2,465	2,440	1,825	2,300
COLOMBIA	640	590	540	590	630	670	700	560	550
ECUADOR	25	25	21	18	25	26	55	45	30
PARAGUAY	60	60	30	60	105	110	120	150	250
PERU b/	515	392	410	400	315	405	375	290	310
URUGUAY	1	1	1	1	-	1	1	1	1
VENEZUELA	71	66	76	98	95	125	105	105	85
TOTAL	5,177	4,497	4,253	4,772	4,960	4,452	4,766	3,671	4,416
WESTERN EUROPE									
GREECE	338	515	500	537	640	500	593	600	510
ITALY	8	9	5	8	4	4	4	5	5
SPAIN	355	270	250	200	260	210	270	200	125
YUGOSLAVIA	18	19	28	16	12	11	12	10	10
TOTAL	719	813	783	759	916	725	879	815	650
EASTERN EUROPE									
ALBANIA	20	25	30	30	30	30	30	30	30
BULGARIA	80	60	70	60	75	60	55	50	50
TOTAL	100	85	100	90	105	90	85	80	80
U.S.S.R.	9,200	8,050	10,800	11,000	11,100	11,180	12,250	11,650	12,200
ASIA AND OCEANIA									
AFGHANISTAN	110	130	100	105	115	150	200	220	250
AUSTRALIA	154	120	89	201	145	140	152	117	160
BURMA	50	50	65	65	65	65	35	50	75
CHINA, PEOP. REP.	8,300	8.100	9,200	10,200	9,800	11,700	11,500	11,000	10,900
INDIA	4,900	4,850	4,400	5,000	5,370	5,530	5,950	5,350	5,000
IRAN	770	760	710	600	965	920	1,095	640	720
IRAQ	60	65	65	65	65	70	70	55	70
ISRAEL	154	103	163	169	186	173	230	225	250
KOREA, REP.	20	20	20	19	18	21	14	14	15
PAKISTAN	2,433	2,470	2,502	3,263	3.237	3,037	2,925	2,370	1,800
SYRIA	710	690	690	725	750	720	670	730	650
THAILAND	200	200	85	150	95	75	90	100	120
TURKEY	2,005	1,845	1,845	2,420	2,505	2,365	2,700	2,215	2,170
YEMEN, REP	3	2	2	3	3	5	12	5	5
YEMEN, P.D.P.	30	23	26	20	21	16	21	15	20
OTHERS	29	31	21	27	25	26	33	32	44
TOTAL	19,928	19,547	19,983	23,912	23,365	25,013	25,757	23,138	22,229

a/ Running bales adjusted for ginnings within season, city crop, etc. except that beginning with 1972/73, data are in bales of 478 lb, net.

b/ Based on ginnings within season.

c/ Revised series.

/...

Table 3 (Cont'd)

COUNTRY	YEAR BEGINNING AUGUST 1st 1968/69	1969/70	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77 Prel.
AFRICA									
ALGERIA	6	8	5	1	2	3	2	5	5
ANGOLA	75	100	142	105	83	140	175	60	60
BENIN	40	42	65	85	80	80	57	46	56
BURUNDI	10	10	10	10	10	10	10	10	10
CAMEROON, U.R. . . .	115	157	66	73	77	40	70	90	90
CENTRAL AFR. EMP.	100	107	91	70	80	76	80	56	70
CHAD	200	300	100	190	180	299	245	300	245
EGYPT	2,013	2,097	2,346	2,351	2,309	2,250	2,010	1,760	1,827
ETHIOPIA	95	85	66	75	80	100	110	110	110
IVORY COAST	70	61	54	91	99	100	110	120	110
KENYA	19	23	25	25	25	25	25	25	20
MADAGASCAR	30	29	37	43	43	54	60	56	65
MALAWI	25	30	33	33	25	32	23	25	75
MALI	75	80	92	117	112	80	106	100	190
MOROCCO	30	31	30	40	40	27	24	10	15
MOZAMBIQUE	205	215	162	210	225	175	109	130	120
NIGER	11	17	16	14	9	6	13	19	15
NIGERIA	200	425	100	175	229	140	240	205	300
RHODESIA	200	200	200	200	100	150	220	100	150
SENEGAL	16	10	19	35	39	55	71	53	75
SOUTH AFRICA	125	90	86	92	82	105	215	125	200
SUDAN	1,090	1,136	1,130	1,125	900	1,290	1,015	490	700
TANZANIA	240	330	360	305	356	300	330	195	325
TOGO	9	9	10	14	10	15	10	16	10
UGANDA	306	300	346	305	300	230	145	115	100
UPPER VOLTA	53	61	30	40	55	46	52	80	110
ZAIRE	75	80	90	95	110	86	75	40	56
ZAMBIA	10	30	10	20	13	8	5	4	5
OTHERS	1	1	1	1	-	5	5	13	20
TOTAL	5,532	6,424	5,863	6,045	5,879	5,738	5,609	4,366	5,102
WORLD TOTAL	56,200	52,730	54,391	59,752	63,163	63,515	64,806	54,583	57,601
SOCIALIST COUNTRIES .	17,615	17,000	20,115	21,305	21,000	22,905	23,080	22,745	23,195
ELSEWHERE	37,505	35,600	34,276	38,447	42,143	40,610	40,726	31,838	34,406

Table 4. Production of long and extra-long staple cotton
(thousand bales)

Country	1967/68	1968/69	1969/70	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76 prel.
	YEAR BEGINNING AUGUST 1ST								
	Long staple								
Brazil	130	145	135	70	150	135	150	150	160
Egypt	1,246	1,241	1,506	1,349	1,423	1,496	1,443	1,280	1,107
India	162	114	133	120	290	590	615	1,365	(1,900)
Mexico	105	143	80	107	86	53	49	8	2
Peru a/	250	347	265	250	279	222	262	210	165
Uganda	80	135	155	195	140	95	115	70	70
United States b/	740	1,819	693	719	1,590	997	750	1,414	1,082
Others	363	456	405	560	582	72?	1,119	1,768	1,118
Sub-total	3,092	4,430	3,537	3,370	4,450	4,223	4,503	6,265	4,644
U.S.S.R.	1,700	1,575	1,550	1,555	1,300	1,425	1,500	1,700	..
World total c/	4,872	5,975	5,087	4,925	5,750	5,648	6,003	7,965	..
	Extra-long staple								
Egypt	760	772	911	997	920	873	815	730	696
India d/	-	-	-	-	-	-	305	107	686
Israel	1	3	5	7	10	15	14	19	12
Morocco	20	30	31	20	40	40	26	24	10
Peru	141	160	125	162	110	95	145	155	116
Yemen, P.D.R.	8	30	23	26	25	25	25	21	15
Sudan	736	860	925	945	935	740	805	810	275
United States	69	70	77	57	96	90	70	91	55
Others	6	1	2	1	1	1	1	6	2
Sub-total	1,752	[illegible]	[illegible]	2,223	2,153	[illegible]	[illegible]	[illegible]	[illegible]
U.S.S.R. e/	640	630	636	866	900	986	865	936	925
Total e/	2,392	2,566	2,734	3,070	3,053	2,830	3,150	2,986	2,730

a/ Based on ginnings within season.

b/ Upland only.

c/ Excluding China.

d/ MCU-5 and varalaxmi varieties together comprise about 95% of the total.

e/ Revised series.

already said that the proportion of linters is zero for G. barbadense, 3-5.5 per cent (sometimes even below 2 per cent) for G. arboreum and G. herbaceum, and 8-12 per cent (sometimes reaching 15 per cent) for G. hirsutum.

An abundance of international technical literature - going back to the end of the last century, and continuing today for new varieties - provides information on the distribution of linters, hull and kernel in cotton-seed. The information is sometimes contradictory, but the usual values,[7] for seeds with a 10 per cent moisture content, are as follows (table 5):

Table 5. Composition of cotton-seed in linters, hull and kernel (percentage)

	Linters	Hull	Kernel	Total
G. hirsutum	9.5-12 average 10.5	36-40 average 38	50-53 average 51.5	100
G. arboreum and G. herbaceum	4-5 average 4.5	43-46 average 44.5	50-52 average 51	100
G. barbadense	0	36-41 average 38.5	59-64 average 61.5	100

It must be noted that some authors determine the percentages with reference to the dehydrated seed weight, which may slightly affect the results.

We shall now examine the three components of the seed.

The linters

Like the lint, the linters are nearly pure cellulose (95-97 per cent α-cellulose). Part (10-20 per cent) of the cellulose, however, is in the form of unwanted oxycelluloses, which are easily detected because they are soluble in alkalis. One must also reckon 0.2-1.5 per cent oils and waxes soluble in ether or benzene, and 0.5-2.0 per cent ash.

The hull

The hull has three main constituents: cellulose, pentosans[8] and lignin. The proportions depend on the same factors as are mentioned above, but remain within the following limits (Murti and Achaya, 1975):

7/ A few varieties exceed the values, but they are exceptions.

8/ Pentosans are the result of combining one molecule of glucoronic acid (in the form of a polyuronide) with 10-16 xylose molecules.

	Percentage	Average
α-cellulose	35-47	44
Pentosans	19-35	30
Lignins	15-25	21
Proteins	3.50	
Fats	C.85	
Ash	1.80	

The kernel

Subject to the same comments on variations in proportions, and the causes, the figures below (table 6) show the usual range of the two most important components of the kernel - oil and proteins. The protein is obtained by multiplying the nitrogen content by the Kjeldahl coefficient (6.25), or by other methods (NH_3 x 5.13).

Table 6. Oil and protein content of cotton-seed kernels (percentage)

	Oil	Protein
G. hirsutum	30-40 average 35	31-41 average 36
G. arboreum	about 36	27-35 average 31
G. herbaceum	about 32	29-37 average 33
G. barbadense	36-42 average 39	31-38 average 34.5

Percentages, of course, are not the only factor: the seed weight, indicated by the "seed index" (weight of 100 seeds, ranging from 7 to 17 grams), is also important, and so is the kernel/seed weight ratio. All these factors are variable and affect the oil and protein yields per hectare.

The kernel contains other components besides oil and proteins, but few studies have been made of them. They include carbohydrates (approximately 14 per cent of dry weight), made of mono-, di- and trisaccharides, pectins, dextranes, hemicelluloses and cellulose, but little or no starch. The main carbohydrate is the trisaccharide raffinose, which accounts for 5-10 per cent of dry weight. The kernel also contains phosphorous derivatives (mainly phytic acid salts and phospholipids), mineral substances, non-protein nitrogenous components, antioxydants, and fat- and water-soluble vitamins.

Many authors give the oil and protein percentages relative to the seed weight, without stating whether they are considering linters + hull + kernel, or only the kernel. The results are very similar, however, since the linters and hull contain very small proportions of those components.

The following can be taken as average percentages:

Table 7. Cotton-seed oil and protein components (as percentages)

	Oil	Protein
G. hirsutum	20	21
G. arboreum	18	16
G. herbaceum	16	17
G. barbadense	24	21

There is a considerable spread around these averages.

The over-all composition of the seed is shown in table 8 below.

Table 8. General composition of the seed

Constituent	as percentage of seed weight
Water	10
Oil	20
Proteins	20
Raw cellulose	23
Ash	4
Other (carbohydrates, etc.)	23

Figure 1 - Component average weights for 100 kg of seed cotton (Buffet, 1977-79)

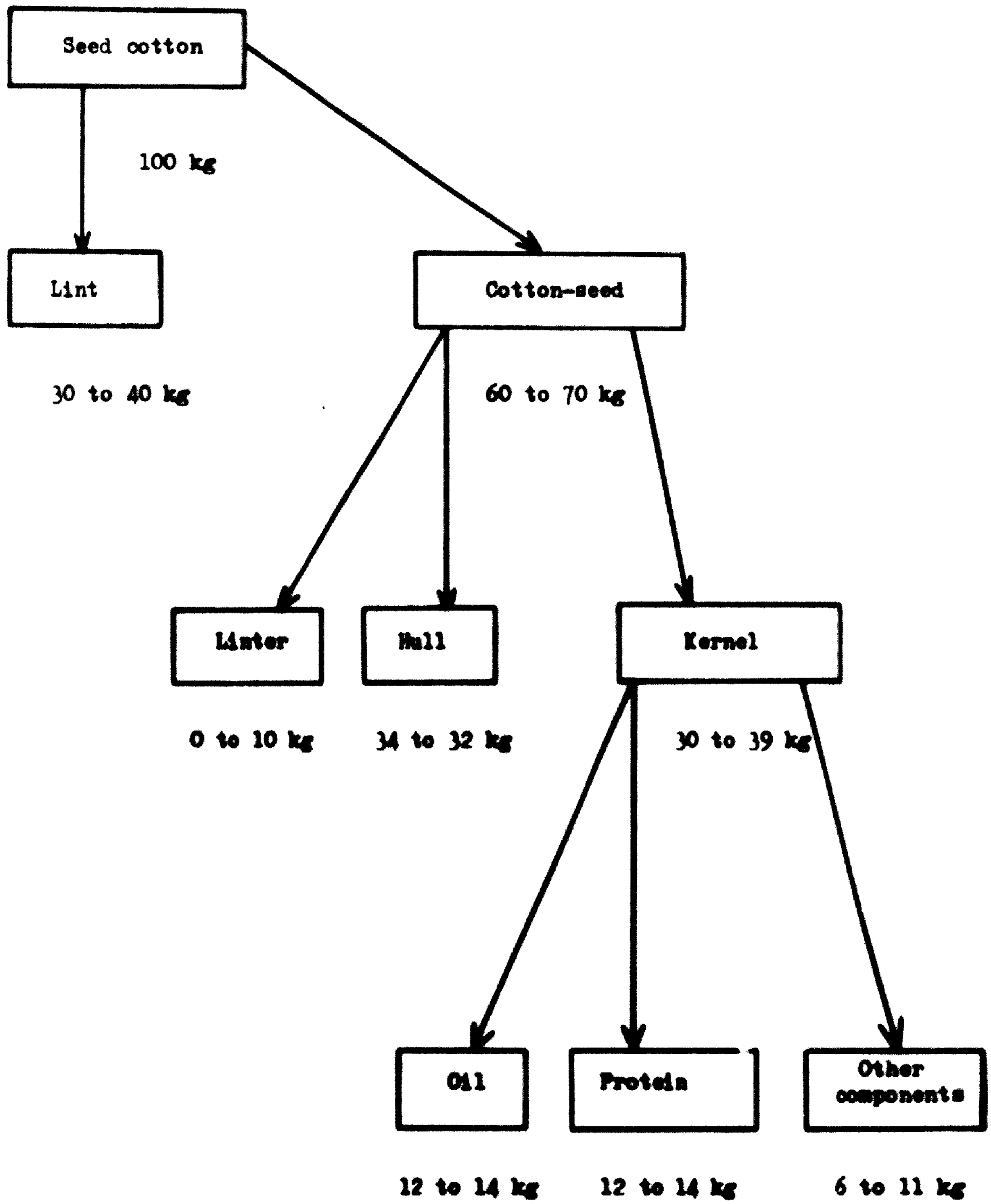

Figure 1 recapitulates the main data on cotton-seed. Since the variations in percentages of the different constituents are very large, approximate limits can be given.

The effects of individual influences on seed composition cannot be gone into in this study. One of them, however, seed maturity, is most important. Starting from the day of fertilization, the fresh seed weight reaches a maximum in five weeks, but at that time the oil weight is only 15 per cent, and the protein and total dry matter weight less than 50 per cent, of what they will be by the ninth week. The seed should therefore be harvested at about the sixtieth day, at least if only these factors are considered, since the oil and protein weights decline subsequently.

G. Gossypol

Gossypol in the cotton-seed

The cotton-seeds, and also the other parts of the cotton plant, are dotted with oval or spherical pigment glands with a major axis 100 to 400 μ long. The glands are distributed irregularly in the kernel. They are enveloped in several layers of epithelial cells, inside which are various pigments. The main such pigment is gossypol, which is yellow in colour and accounts for 20-40 per cent of the weight of the gland and 95 per cent of the weight of pigment.

There are other substances in the pigment gland, besides gossypol: gossypurpurin (purple); gossycaeruleum (blue), which is not a constituent of the raw seed but appears during heating; gossyfulvine (orange and very rare), which is found mainly in seeds stored in very damp conditions; gossyverdurine (green); flavonides; anthocyanins (violet); carotenoids; chlorophyll; resins; etc.

It is therefore understandable that the pigments give an orange/yellow colour to the cotton-seed oil and flour.

Gossypol is insoluble in water. When the pigment glands of a ground kernel are put into water, however, their membranes break down rapidly, usually at a single point, and the pigments flow into the water, from which they then precipitate.

Gossypol is soluble in methanol, ethanol, isopropanol, n-butanol, ether, ethylacetate, acetone, chloroform, carbon tetrachloride, cold diexane, diethylene, glycol, and pyridine; it is slightly soluble in glycerol, cyclohexane and in high-boiling (100°-110° C) petroleum ethers; it is insoluble in low-boiling (30°-60° C) ethers. It also dissolves in cotton-seed oil, alkaline solutions and certain salts.

When solvents miscible with water (methanol, ethanol) are used, the water breaks down the gland membranes, and the gossypol dissolves in the solvents, with varying degrees of rapidity and yield, depending on the type and proportion of the products.

Gossypol is a phenolic binaphthaldehyde.

Gossypol content of various species of cotton-seed

The classical varieties of cotton-seed all contain gossypol, and this is why they are called "glanded cotton-seeds", to distinguish them from the glandless cotton-seeds, which will be dealt with elsewhere.

The gossypol content depends on many factors, but is between 0.3 and 2 per cent of the seed weight.

The content is generally lower in G. herbaceum than in G. hirsutum, and highest in G. barbadense, but the test results are so contradictory that not too much reliance must be placed on this.

The disadvantages of gossypol

Colouring of the seed and products derived from it

Storage, especially when the seed is damp (more than 10 per cent water) and its biochemical processes generate heat, leads to the formation of free fatty acids and the breakdown of pigment glands. Gossypol spreads throughout the seed, oxidizes, and combines with oil and proteins and darkens them.

"Pink white discoloration", which will be looked at in chapter V, on cotton-seed oil, is an associated phenomenon: the eggs laid by hens fed with cotton-seed cakes show a strange colouring after being stored for some time - the white turns pink or red, and the yolk turns brown or olive-green. This is due to the combined action of gossypol and of two fatty acids present in small quantities in cotton-seed (the cyclopropene acids). The latter modify the egg vitelline membrane of the egg, thus allowing gossypol to penetrate to the yolk and change its colour.

The lowering of the nutritive value of proteins and toxicity

Many works have shown that the less gossypol the cotton-seed flour contains, the higher its nutritional value.

During the boiling of crushed cotton-seed, which is the first step in oil extraction, a bound gossypol appears as the result of a combination with the protein amino acids, and especially with lysine.[9/] This gossypol-bound lysine can no longer be assimilated. Bound gossypol, moreover, reduces protein digestibility by inactivating the proteolytic enzymes.

Once it has appeared in cotton-seed flour, gossypol is very difficult to get rid of.

Free gossypol also has a slightly toxic effect (loss of weight, etc.) upon non-ruminants and probably on man. The effect can be diminished or suppressed by the addition of ferrous salts or potash. Gossypol is well-tolerated by ruminants, however.

Cotton-seed has long been eaten by certain African tribes, generally during famines or in the periods between food-crop harvests. Serious oedemas have been observed, but most of the ethnic groups concerned know how to inactivate gossypol partly by such cooking techniques as adding potash in the form of ash water.

<u>The separation of pigment glands from cotton-seed</u>

Pigment gland flotation

The pigment gland flotation process was developed at the Southern Regional Research Center (SRRC) by Boatner's group in 1946. The group noted that the density of the pigment glands (1.26-1.38 g/cm^3) was lower than that of the extraglandular kernel tissue (1.40-1.45 g/cm^3) and the hulls (<1.45 g/cm^3). They exploited these differences by disintegrating cotton-seed flakes violently in a slurry of hexane and various other heavy solvents mixed in proportions that gave a resulting specific gravity of 1.378 g/cm^3. The glands that float to the

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9/ The principal binding site is thought to be the free ϵ-amino-group of lysine.

surface can be mechanically separated from the oils and the gland-free tissues, which precipitate out. The degree of comminution must be set carefully: if it is too low, too much gossypol remains in the tissue; if it is too high, the difference in density between the tissue and glands is too small for separation to take place. Another difficulty is the need to use heavy solvents, which were high-boiling and toxic.

Differential settling

The disadvantages of gland flotation led Vix and his students to develop a differential settling process which depends on the fact that fine cotton-seed kernel particles (2-40μ) settle more slowly in a hexane suspension than particles of hull, pigment glands or kernel particles larger than 40μ. Although the meal produced by the process has as low a gossypol content (0.006 per cent) as that produced by the flotation process, it was not economically attractive to industry.

Air classification

Air classification is a process developed by Meinke and Reiser. Cotton-seed kernels with a controlled moisture content are ground, the oil is hexane-extracted, and the solvent-free meal is disintegrated in an attrition mill. The meal is finally air-classified. From the original meal containing 1.08 per cent free gossypol and 50.6 per cent protein, air-classified cotton-seed flour containing 0.88 per cent free gossypol and 62.4 per cent protein has been obtained.

Liquid cyclone process (LCP)

The liquid cyclone process, developed originally by Gastrock _et al._, and subsequently refined by Gardner _et al._, is the first economic and workable process capable of removing pigment glands from cotton-seed to produce a gland-free, high-protein, edible flour. It is applied to dehulled seeds that have been ground in hexane into small particules. The pigment glands do not break down if the meal has less than 4 per cent water.[10/] The suspension is then fed

10/ Recent work has shown that the glands do not break down when the water content is well above 4 per cent, provided the water contains certain mineral salts such as sodium, aluminium, ammonium, cadmium or copper sulphate; or calcium, ferrous or magnesium chlorides. Sodium sulphate is especially interesting, because it does not affect protein solubility. The LCP process can thus be employed with various acqueous solutions.

into a cyclone tangentially under pressure. This establishes within the cyclone a swiftly rotating body or vortex of fluid. Centrifugal forces cause the heavy particles, which include the pigment glands, to move to the walls of the cyclone, while the light particles and most of the liquid are concentrated on its axis. Separation is then simple: the heavy particles move to the bottom of the cyclone where they are discharged; the bulk of the liquid, which contains the light particles, moves upwards along the axis and is discharged through an opening at the top.

A mill using the LCP process was built in 1973-1974 in Lubbock, Texas (United States). Using cotton-seed kernels as raw material, it works as follows:

The cotton-seed kernels, which contain about one-third oil and two-thirds solids, are first dried to reduce the water content to below 3 per cent so as to avoid rupturing the pigment glands during the process. Drying takes place at about 80° C, because too much heat degrades the proteins.

After drying, a pneumatic system delivers the kernels into a pair of pin-mills, which grind the kernels into particles 0.2-0.3 mm thick. Finer grinding (as with flaking mills) would rupture the pigment glands.

The milled kernels are then fed into a mixer, where hexane is introduced. The slurry is diluted to 45 per cent with additional solvent so as to facilitate separation in the cyclone.

The slurry, containing 20-22 per cent solids,[11] is agitated as it is fed into the cyclones. There are two sets of double cyclones (each consisting of a primary and a secondary cyclone). This arrangement increases throughout and produces better separation.

The liquid cyclones classify the slurry into a gland-free fraction containing 13-15 per cent of high-protein solids, and a gland-rich coarse meal containing 43-45 per cent solids. After adjustment of classification, the two fractions undergo different treatments.

11/ This solids level is a compromise between the fluidity needed in the cyclone, solvent costs, and yield.

The gland-free fraction is fed into a rotary vacuum drum filter that removes most of the solvent. During filtration, the oil content of the solvent-free meal is reduced to about 0.6 per cent. Residual solvent is removed in a rotary blender: the cake is heated to 82° C, and nitrogen gas is injected to strip the remaining solvent (which must be below 50 ppm). During stripping, the temperature may be increased to 93° C for maximum bacteria kill. Because of the absence of water in the flour, the heating has little or no effect on protein quality or the colour of the flour.

The flour is then cooled to 43° C and collected in drums with double polyethylene liner bags under sterile conditions. The composition of this flour, which is intended for human consumption, is given in table 9.

Table 9. Composition of cotton-seed flour intended for human consumption

Constituents	Percentage
Water	3.66
Oil	0.62
Free gossypol	0.03
Total gossypol	0.12
Nitrogen	10.54
Protein (nitrogen x 6.25)	68.40
Available lysine, g/16 g N	3.94
Fibre	2.4
Ash	7.54
Residual hexane	(35 ppm)
Carbohydrates and other constituents	17.23

Source: Plains Co-operative Oil Mill documents.

The gland-rich fraction contains 3-5 per cent gossypol, proteins, solvent (with oil), and water. The diverted protein is less than 35 per cent of the total. The slurry is pumped into a tank for dilution with hexane and from there into a second set of two cyclones for further density separation. The heavy fraction from these cyclones is pumped into a mixing vat feeding a rotary vacuum filter. The hexane is removed together with the oil. The filter cake is freed of residual solvent, which is recovered, and is then ready to be used in cattle feed.

The drawback of the process is that the low-gossypol fraction accounts for only part of the kernel weight, as is shown in table 10.

Table 10. Composition of the various cotton-seed fractions in hexane extraction

100 kg of cotton-seed gives	kg
Linters	10
Hull	38
Oil	18
Low-gossypol flour	18
High-gossypol cake	13

Source: Plains Co-operative Oil Mill documents.

From a practical standpoint, an LCP plant for food-grade cotton-seed flour must be associated with a cake mill, because:

- Food for human consumption requires high-quality raw material with a minimum of hulls;
- The separation and recovery of hexane and oil are more economical when they are carried out in a larger mill's facilities;
- The gossypol-rich by-product can be combined with other animal feed stuffs produced by the oil mill.

The Lubbock mill was built with an initial daily capacity of 25 tons of low-gossypol flour. The capacity can be doubled subsequently.

Removal of gossypol from cotton-seed oil

Gossypol can be removed from cotton-seed oil by several chemical reagents. It is well known that the treatment of raw cotton-seed oil with alkalis or alkaline salts removes not only free fatty acids (used as soap stock), but also gossypol. It is reported that soap stock obtained from cotton-seed oils in

India contain as much as 20 per cent gossypol. Other chemicals used to remove gossypol from cotton-seed oil include sodium hypochlorite, p-aminobenzoic acid, anthranilic acid, diethylenetriamine, hydrogen peroxide, borax, p-aminosalicylic acid, and sodium silicate.

Removal or inactivation of gossypol contained in cotton-seed cake

Various agents can be used to remove gossypol from cake, or inactivate it.

The addition of 2 per cent stearylamine to kernels during cooking in a high-humidity environment yields cakes with a level of free gossypol below 0.01 per cent. The cakes have good nutritional values and do not cause any disagreeable coloration of hens' eggs.

Gossypol can also be extracted with ether enriched with acetic acid, or with other solvents (acetone-azeotropic mixtures such as hexane-acetone-water or butane-acetone-hexane-water, and additives, or a solution of ethanolamine in ethanol).

Gossypol can be inactivated by several ferrous salts, calcium hydroxide and potash.

The development of glandless cotton-seeds

Techniques for removing gossypol from cotton-seed flour have not become widespread, since they require complicated, high-cost devices that do not remove the gossypol completely.

A more attractive approach is offered by glandless cotton-seed, which appeared in 1959, as a result of work by the American geneticist McMichael.

An enormous selection campaign began immediately to develop varieties suitable for the United States, and extensive research was done to determine their characteristics and advantages. The work done at the USDA Southern Regional Research Laboratory in New Orleans and in the Food Protein Research and Development Center at Texas A & M University deserves particular mention.

The two genes now used by the geneticists who are developing glandless varieties were reported by McMichael and are designated gl_2 and gl_3. The first approach taken was to use backcrossing. It was hoped that the glandless genes

gl_2 and gl_3 could thus be incorporated into existing varieties and that within a very few years, all the United States cotton-growing areas would be planted with glandless varieties.

This required further research work, which is still going on. The original Gregg 25 V and Watson gl 16 glandless varieties were replaced by others whose fibre yields are practically the same as those of the glanded varieties grown in various areas of the United States (table 11).

Table 11. Fibre yields of glandless breeds and glanded controls in some improvement programmes (United States, 1975)

	1	2	3	4	5	6	7
Best glandless breed (lb/acre)	671	994	842	960	647	804	735
Glanded control (lb/acre)	682	929	828	978	599	723	729
Glandless breed yield as percentage of glanded control yield	98	107	102	98	108	111	101

Source: Buffet, 1977.

The preference shown by some (but not all) species of insect for glandless varieties by some insects is a matter of greater concern: the resulting differences in yield depend on several factors and may be serious.

In California, for example, the acala 68160 glandless variety gives a yield 99 per cent of the acala average, unless it is attacked by Lygus, when the yield falls to 83 per cent if contamination is high.

Outside the United States, Egyptian research produced a glandless variety derived from G. barbadense called Bahtin 110, obtained by treating Giza 45 with radioactive phosphorus. Bahtin 110 produces a less abundant crop than Giza 45, the ginning yield is 3 per cent higher, and the staple is shorter and weaker.

The Indian Badnawar glandless (Bgl) and Indore glandless (Igl) varieties are also more liable to attack from insects than the glanded Badnawar I control variety; if insecticides are used, however, yields for at least some glandless subvarieties (Bgl 6, Igl 68-1, Igl 68-2, Igl 68-3) are higher than those of the control.

Other trials have also been carried out in Brazil, Iran, Mexico, and the Syrian Arab Republic, and in a number of African countries.

Generally speaking, glandless varieties require more pesticides and more careful surveillance so that rapid action can be taken against the insects, and other pests (rats, mice, rabbits, etc.).

Care must also be taken that glandless seeds are not mixed with glanded seeds, and this implies strict organization at every stage of seed production and processing.

It must be remembered that for the producer, the seed is only a minor by-product of the staple; in the United States, for example, the values of cotton lint and seed produced per acre in September 1976 were (in dollars):

	Dollars/acre	Percentage
Seed	48.00	13.30
Lint	312.00	86.70
Total	360.00	100.00

Although the absence of gossypol will reduce the cost of refining the oil and will permit the use of cotton-seed protein for human and monogastric animal feeding, the increase in the value of the seed may not be a sufficient incentive for the farmer to strive to adapt.

It may be hoped, however, that the breeders will manage to make the glandless varieties more insect-resistant, so that their cultivation will spread gradually. Developing countries that are short of proteins and grow cotton could also take steps to encourage the glandless varieties.

The composition of glandless seed has been thoroughly studied. Besides the fact that there is practically no gossypol (0.002-0.01 per cent) there is no significant difference between glanded and glandless seeds. The oil yield of the glandless varieties is perhaps slightly higher.

Standards for gossypol content in cotton-seed products

The FAO/WHO/UNICEF Protein Advisory Group (PAG) has set a maximum gossypol content for cotton-seed protein concentrates (delipidised flours) for human consumption:

	Maximum percentage of flour weight
Total gossypol	1.2
Free gossypol	0.06

This rate has been used as a basis for legislation in various countries. In India, for example, the limit is 1.1 per cent for total gossypol and 0.065 per cent for free gossypol. USDA lowers the limit for maximum free gossypol to 0.045 per cent.

II. STORAGE, TRANSPORT AND GINNING OF SEED COTTON

A. Risks of deterioration during storage

Internal or external biochemical changes may seriously affect the quality of the seed at various stages:

When it is still attached to the plant in the field;

During transport and storage before ginning;

During storage after ginning.

Among the external changes - mainly mould contamination - one of the most difficult to deal with is the formation of toxins, which may persist in cake and meal.

Internal biochemical changes

Internal biochemical changes manifest themselves by the release of heat and an increase in free fatty acid content, which together cause the colour of the oil and meal to darken.

The increase in temperature also lowers the quality and reduces the length of the staple. The main factor responsible for the increase is moisture; there is no increase if the seed contains less than 10 per cent water. The hull is generally damper than the kernel.

If seed is stored damp, its temperature can reach 55° C within ten days or so.

The heat released comes from the combustion of kernel carbohydrates and pentosanes in the hull: the proteins are not metabolized, but are partially hydrolised and denaturated. The lipolysis of the oil causes, as has already been mentioned, an increase in the free fatty acid content.

Contamination by micro-organisms

Contamination by micro-organisms takes place only when the moisture content of the seed exceeds 15 per cent.

The micro-organisms likely to attack the seed are either bacteria (xanthomonas) when the moisture content is very high, or, as is more often the case, fungi, the two main species of which are penicillium and aspergillus (flavus, glaucus, niger, etc.).

These micro-organisms, especially the fungus, cause a rise in fatty acid content.

Aspergillus flavus is particularly dangerous, because it secretes aflatoxin, a very dangerous carcinogenic substance that is unaffected by subsequent processing and persists in the flours and oils.

Aspergillus flavus contamination appears on the plant itself as a result of action by insects or high rainfall, at harvest time, or during storage. The problem has been thoroughly studied for several years. There are four main ways to fight Aspergillus flavus:

Preventing the growth of Aspergillus flavus mould in the raw material;

Using techniques to separate contaminated products from uncontaminated ones;

Chemical treatment to inactivate the aflatoxin;

Solvent extraction to remove the aflatoxin.

The first method of inhibiting fungus growth is to harvest the cotton-seed when it is dry, or to dry it. It is reckoned that there is no risk if the moisture content is below 10 per cent. During storage, the temperature must be outside the range between 28° C and 37° C, which is the most favourable range for Aspergillus flavus contamination. The use of chemical agents to counter moulds (maleic hydrazide, or propylene glycol dipropionate mixed with 1,3 dimethyl 4,6 bis benzene) are not recommended, since the agents themselves may be carcinogenic.

Autoclaving of damp toxic cotton-seed cake can reduce the aflatoxin content, but the nutritive value of the cake may be affected. Ammonia may also be used.

Ozone oxydation of cotton-seed flour for two hours destroys 90 per cent of the aflatoxin.

An even more certain method is to extract aflatoxin by polar solvents such as an azeotropic mixture or acetone-hexane-water, 2-propanol and water, and solutions of acetone or ethanol.

Such treatments entail additional costs which it must be possible to recover on the end-product.

B. Handling and storage of seed cotton

In the United States and other producing countries, it was normal practice to dry seed cotton in the sun after harvest - atmospheric conditions permitting - by spreading it on canvas or wattle mats. The seed was gathered at the end of the day and stored in well-aired sheds for a week, during which time the low heaps were turned over at regular intervals.

In the United States, this classical farm drying has been losing ground for some forty years for the following reasons:

- The development of mechanical harvesting shortens the harvest period; so the seeds are delivered to the farm in vast quantities;
- In addition, because the average cultivated acreage has increased, it is difficult for the producers to keep large enough sheds;
- The cost of labour (if available at all) becomes prohibitive;
- Farmers wish to be paid for their crops quickly, and try to dispose of the seed cotton as soon as possible;
- Means of transport have also developed and make it possible to move the seed rapidly from the farm to the ginning factory.

The seed cotton is moved from the plantation to the factory by trailer. If, when the harvest is at its peak, the factory is not equipped to store the seed cotton, the trailers may accumulate at the farm or the mill, and this can seriously affect the quality of the lint and grain within only a day or two.

If pallet trailers are used, fewer vehicles will be needed, but the time that passes before ginning is not reduced.

Worse still, seed cotton absorbs moisture during storage from the green vegetable matter harvested with it. This vegetable matter contains an average of 40-60 per cent water before the complete drying of the leaves and before the frosts.

The traditional system for unloading seed cotton at the ginnery consists of a blower unit, a separator, and an automatic control unit. The blower supplies sufficient air to a telescopic tube to suck the seed cotton from the trailer, and the separator separates the seed cotton from the air stream. The automatic control unit consists of a hopper, two vacuum wheels, and a metering device: it enables the seed cotton to be directed to drying, cleaning and ginning units at the rate desired.

Another method eliminates pneumatic handling. The trailer load is dumped into a large hopper and conveyed mechanically to the automatic control unit.

American ginneries that are supplied with seed cotton in large volumes (for the reasons stated above) are increasingly inclined to dry it artificially, not only to avoid the risks of the fibre and seed deteriorating, but also to facilitate fibre removal.

A further reason is that storing seed cotton before ginning later in the season may be a better economic alternative than building additional ginning facilities that would be used for only a short period each year.

Research workers in the United States have studied the relationship between the atmospheric humidity and lint and seed moisture content, and also the effect of artificial drying at different temperatures on the properties of the lint and seed.

Seed cotton is dried artifically only if it is damp and must be stored for some time before ginning.

Drying can be done by forced draught at normal temperature, or by hot air. In the latter case, the temperature (70°-105° C) does little to reduce the moisture content (it is reduced by about 0.7 per cent only), but inhibits the enzymes responsible for the formation of free fatty acids. At about 105° C, there is a risk that the protein may deteriorate, and temperatures above 90° C are apt to "cook" the lint, which reduces its strength and alters its properties. It is therefore better to dry twice with air at 65° C rather than once at over 90° C.

The best conditions for ginning are when the lint has a moisture content of approximately 7 per cent when it is separated from the seed. This is why damp seed cannot be ginned satisfactorily without drying. Drying can take place at various stages: in the drier before the seed enters the ginning cycle proper, or after a first cleaning in the feed-cleaner of the gin.

C. Ginning

Preliminary cleaning

After the first drying, the seed cotton is usually pre-cleaned, so as to remove the impurities (bits of leaf, scraps of stem and bark, sand, dust, and so forth). The machines used are drums (4-15 in number) fitted with pins or teeth and revolving on top of screens. They are placed in series. The machines not only clean the seed cotton, but also make it fluffy, which facilitates subsequent operations.

When the seed cotton contains a large amount of sand, dust and unopened capsules, a special device called an "airline-cleaner" has to be used. The cleaner opens most of the closed capsules and removes many of the impurities. Seed cotton is fed into the cleaner by a stream of air that is sometimes heated.

The next step is extraction, which completes the preceding cleaning operations by removing the coarse impurities and the capsule waste. Extraction works on the carding principle: a large-diameter, slowly-rotating drum fitted with saw teeth picks up the seed cotton; the stems, straw, empty capsules and other coarse foreign matter are then removed by smaller toothed drums around the edge. This machine, known as a "big burr machine" or "master-extractor", is particularly necessary when the seed is harvested mechanically (or carelessly by hand).

The seed cotton can now be conveyed either to the dispenser which distributes it by an endless screw between the gin feeders (one dispenser feeds two to five gins) or into a second drying and cleaning cycle.

In any event, when the seed cotton reaches the gins, it is cleaned again, since most gins are fitted with cleaner-feeders or cleaner-extractor-feeders that perform three functions: mechanical or manual regulation of the feed rate into the gin, cleaning of the seed cotton by means of small spined or toothed drums, and sometimes hot air drying. The units are efficient enough to be able, on their own, to clean seed cotton that has been carefully picked by hand.

The ginning itself

There are two main categories of gin:

Roller gins

Roller gins are the older type. They consist of a roller, a fixed blade and a working blade, the movement of which separates the seed from the lint caught between the leather-clad roller and the fixed blade. There are single-roller gins with two moving blades (double-action gins), and also two-roller gins. The capacity of a two-roller gin is about 1.5 times that of the single-roller gin.

Saw gins

Saw gins have a much higher capacity and are therefore used in modern mills, especially in the United States.

The seed cotton coming from the feeder enters a chamber the floor of which is made of bars. Inside the chamber is a battery of saws rotating about a horizontal shaft. The saws are toothed discs regularly spaced along the shaft and firmly attached to it. Each gin has 80-120 saws rotating at 500-800 rpm. The saws run between the bars. They bite into the bulk seed cotton, and catch the lint and draw it through the bars. The bars retain the seeds, which are evacuated elsewhere.

The lint is removed from the saws either by a brush drum, which rotates at high speed in the opposite direction, the tufts meshing deeply with the saw teeth or by air blown tangentially downwards to the saws ("air-blast system"). The air-blast system simplifies the construction and maintenance of the gin, but the lint is less easy to remove when it is damp.

It is also possible with saw gins to separate impurities left over after preceding cleaning operations. This stage is called "moting" (upper and lower).

Comparison of roller gins with saw gins

For the comparison to be fair, the following variables must be taken into account:

Lint quality

Roller gins produce a lint that tends to be packed or wadded or to form small knots, while saw gins produce a fluffy lint, of a more uniform quality. Saw gins may cut the staples and cannot be used for extra-long staples.

Lint purity

Roller gins break many of the seeds, which get mixed with the lint, while saw gins give a very clean lint.

Seed quality

Saw-ginned seeds are whole and clean, but retain more linters.

Capacity

A saw gin has a capacity some 27 times higher than a two-roller gin and 40 times higher than a single-roller gin.

Material yield

Losses are greater with a saw gin. For example, a roller gin will give 33-34 per cent lint, compared with 32 per cent for a saw gin, from the same seed cotton.

Investment

A saw gin costs far more than a roller gin. It is therefore logical to run it longer, if possible four to five months a year, and this entails storage.

Labour

For 1 kg of lint, the labour cost is far lower with a saw gin, but the minders must be more skilled.

Power

A saw gin uses more power than a roller gin, but the converse is true if the cost is calculated per kilogram of lint produced.

Maintenance

Maintenance of a saw gin is more complicated and requires the purchase of more expensive spares.

Treatment of lint after ginning

Cotton that has been harvested mechanically cannot be perfectly clean after ginning; so "lint-cleaners" of various types are used. Some use only an air stream to clean the lint: others comb it with a toothed drum. Sometimes both devices are used successivly, but mainly for low-grade lint.

On leaving the lint-cleaners, the lint is blown into condensers that shape it into sheets, and is then pressed into bales.

III. COTTON-SEED IN HUMAN NUTRITION

Malnutrition due to a lack of proteins, particularly among children, is frequent in many countries where cotton is grown. For the last forty years, therefore, and especially since 1960, people have thought about developing the use of cotton meal as food. Practical applications have been few, however, and relate to only a small percentage of the cotton-seed available in the world. Pioneering attempts have nevertheless shown that, provided certain technical conditions are met (see below), such development is both desirable and possible with traditional seed containing gossypol, and particularly with seed that does not contain it.

Seventy per cent of the world cotton-seed crop in 1975 was processed to obtain oil and cake; the remaining 30 per cent either goes directly, in the form of whole seed, to feed ruminants, or is used as fertilizer or fuel.

Unfortunately, part of the cake is unsuitable for feeding monogastric animals owing to the presence of free gossypol, the disadvantages of which have been mentioned above. Such cake is even less suitable for human consumption. The following pages will show what must be done to improve quality and obtain an edible flour. It must be remembered, however, that oil is considered to be the main product of the mills, and that cake (or meal) is regarded as a by-product. The millers are therefore not much inclined to improve cake or meal quality; and are interested in doing so only if oil yield and quality are unaffected.

A. Undesirable constituents in cotton-seed flour

Gossypol and its effect on lysine content

The most undesirable constituent of flour intended for human consumption - from now on simply called "flour" - is gossypol. Free gossypol is toxic, and gossypol linked to protein amino-acids reduces the nutritional value of the acids, particularly by lowering the available lysine content.12/

The more the kernels are cooked before extraction, the lower the free gossypol content. Excessive cooking reduces the protein value, however, not only because gossypol binds with lysine and other amino-acids, but also because

12/ Other amino-acids, such as glutamic and aspartic acids, are also made partly unavailable.

heat encourages other reactions, such as the "Maillard" reaction, which binds some glucides to the amino-acids: the kernel raffinose has a particular tendency to bind with lysine. Consequently, during the cooking that precedes oil extracting, a compromise must be found whereby the percentage of free gossypol is reduced as far as possible without degrading protein quality too far.

It was mentioned in chapter I.G. that various processes can be used to extract or chemically inactivate cake gossypol. Some of these processes can be applied to the flours, but it is not always necessary to do so, since suitable precautions can be taken to obtain flours in which the free gossypol and total gossypol contents are quite satisfactory.

The use of gossypol-free seeds is a better solution technically and has a promising future. It must be noted, however, that there is still a need to avoid any overcooking that might cause "Maillard" reactions.

It is interesting to note the available lysine content of cotton-seed proteins in relation to the oil extraction process used. Calculated as percentage of protein by the Kjeldahl method (nitrogen quantity x 6.25), the content is as follows:

- About 4.5 per cent in the kernel itself[13] before extracting (according to the authors, the range is from 3.2 to 6 per cent, but an average value of 4.5 per cent seems the most likely). This reference level can be used to measure the effects of subsequent processing;
- From 2.5 to 3 per cent in cake or meal from which the oil has been extracted by continuous screw press;
- From 3.1 to 3.6 per cent in cake or meal from which the oil has been extracted by solvent (hexane) after screw pressing;
- About 3.4 per cent in cake or meal from which the oil has been extracted directly by hexane solvent extraction;
- From 3.7 to 4.4 per cent in cake or meal from which the oil has been extracted by azeotrope-acetone-hexane-water extraction.

These percentages show that there is little hope of arriving at a lysine content greater than 3.6 per cent when the oil is extracted by screw press, while it rises to 4.4 per cent if certain solvents alone are used, provided that proper precautions are taken during the prior processing steps.

13/ In this respect, there is no significant difference between species of cotton plant.

The percentage of available lysine which depends upon its association with gossypol and also with the flour glucides, is a fair index of the nutritional value of the cotton-seed protein. The value can be measured by different methods, the most usual being to compare the increase in weight of young rats fed on casein with that of rats fed on the proteins in question. A protein efficiency ratio (PER) is thus obtained, it being assumed that the PER of casein is 2.5. Cotton-seed protein has a PER of 1.5 to 2.2 and is correlated with the available lysine content. An additional proof is that the PER can be increased by adding lysine. This proves that lysine is the first limiting factor.

The other limiting amino-acids in cotton-seed protein are isoleucine, methionine and threonine, as will be seen later (see table 14).

Undesirable constituents other than gossypol

There are numerous undesirable constituents other than gossypol. They include pesticides, solvents, machine lubricating oils, toxic vegetable particles gathered with the cotton-seed, aflatoxins (see chapter II.A.), bacteria, insect scraps, and rodent hair.

There are also two cyclopropenic acids (malvalic and sterculic) which, together with gossypol, cause the colouring of egg yolks (see chapter I.G.), and may be found in the flour if the oil content is above a negligible level. Their toxicity for man has not been clearly established but it is preferable to remove them.

B. Precautions to be taken to obtain good-quality flours

The choice of cotton-seed

It is obvious that the raw material must be of first quality. A document entitled "Cottonseed protein concentrate", drafted in 1965 by the Protein Advisory Group (PAG) of WHO/FAO/UNICEF and revised in 1970, suggests that flour for human consumption should be produced from high-quality cleaned cotton-seeds, with less than 1 per cent foreign matter (including seeds of other species), less than 10 per cent moisture, and less than 1.8 per cent free fatty acids in the oil analysis. The proportion of bleached kernels should not exceed 5 per cent.

Gossypol is not mentioned here (it will be covered later, in connexion with the finished product), but it is advisable to use seeds that do not contain too much gossypol.

For aflatoxin, PAG assimilates cotton to other proteaginous plants: there should be none detectable, which implies a limit of 30 ppm (30 mg/kg).

The treatment undergone by the cotton-seed after it has been separated from the staple will be dealt with in chapter IV. A brief description is given here to provide comment relevant to meal.

Storage

Particular care must be taken with storage so that the moisture content remains below 10 per cent: artificial drying might be necessary.

Cleaning, delinting

These operations must be carried out more thoroughly than usual. It is therefore advisable to install additional cleaning machines.

Dehulling and hull separation

Traditional machinery is used but must be adjusted so as to remove the hulls as completely as possible. This has an economic disadvantage, however, since an excessive proportion of the oil is removed with the hulls.

The percentage of hull remaining is one of the factors that affect the final protein content of the product. United States cotton-seed cake intended for non-ruminant feed generally contains 41 per cent protein, but a proportion of 43 per cent and even more can be found. For flours from which practically all the hull scraps have been removed, the minimum protein content is 50 per cent (see chapter III.C.).

Rolling and cooking

The crushed cotton-seed kernels, which will be simply called "meal" where there is no ambiguity, have to be dampened if their moisture content is below 10 per cent. The final humidity must not exceed 12 per cent.

The flakes should preferably be less than 0.254 mm thick.

As has already been mentioned, the best conditions for cooking meal represent a compromise between a desire to get rid of the free gossypol and a concern not to degrade protein quality. A good method is to raise the moisture content of the flakes to 12-14 per cent and heat them rapidly to 93° C. The cooking time depends on the oil-extraction process: 75-85 minutes for press extraction, or 30-40 minutes for pre-pressing followed by the use of a solvent. The temperature on completion of cooking must not exceed 110° C.

The foregoing applies to traditional cotton-seeds. With gossypol free seeds, less heating is required, because there is no free gossypol to remove; so a lower temperature can be used, and this degrades and colours the protein less.

Oil extraction

Hydraulic presses - very seldom used nowadays - and screw presses inactivate most of the free gossypol but also reduce the nutritive value of the protein considerably because of the pressure and the excessive temperature. This is clearly shown by the low available lysine content. An acceptable flour can be obtained only if there is a large amount of water left in the meals, as a result of which the flour has a high oil content (6.5 per cent, for example). This affects profitability adversely, since the prime aim of milling is to produce oil.

Oil extraction by pre-pressing followed by solvent action leaves very little free gossypol and oil in the flour, and degrades the protein less. It is therefore more suitable for flour production, although, as has been seen, the lysine is still partially bound.

It was long thought that direct solvent extraction did not remove sufficient free gossypol and was therefore suitable only for glandless seeds. It was acknowledged, however, that the protein value was well preserved. Since 1960, much research work has been done on the subject. A process developed by the Southern Regional Research Laboratory (SRRL) in New Orleans (United States) uses an acetone-hexane-water azeotropic mixture; the Vaccarino process used in Sicily (Italy) used acetone alone. Both processes remove nearly all the free gossypol, without degrading the protein. The available lysine content is almost the same as the protein content of the kernels before processing. There is very little residual oil in the flour. However, the SRRL method has been said to give a bad taste to the flour. It also requires some adaptation of plant, since mills extracting oil by solvent use hexane, and it is not clear that the higher sale price obtained through the improvement of oil and flour quality offsets the additional investments. Consequently, neither the SRRL process nor the Vaccarino process has had much success (except in Italy for the latter). See the LCP process described in chapter I.G.).

Cooling, grinding and screening of cotton-seed flour

The flour is cooled for several days before grinding.

Grinding, together with the subsequent screening, makes it possible to adjust the proportion of hull fragments to the desired level. It completes the hulling, which cannot reduce the hull-scrap content of the meal to below 10 per cent without lowering the yield excessively (some oil and meal parts are removed with the hulls).

Grinding is done with traditional machines running at normal or slightly faster than normal speeds. Hammer mills seem to be the most appropriate and consume less energy than attrition mills, although this depends on the percentage of residual hull.

Fine screening is difficult when the flour contains more than 3 per cent oil.

Some grinding machines employed in the United States use differential separation by air stream. The results are more satisfactory than those of screening, provided there are no linter fragments that could be sucked up with the flour (although they can be removed by a final screening).

C. Characteristics of the flour

The PAG standards

This text, of which the part concerning raw material is cited in section B of this chapter, stipulates that the processing mills must comply with the usual sanitary regulations governing the manufacture of food for human consumption.

The oil extraction processes must be suited to the production of flour; the temperature, in particular, must be carefully controlled so as to destroy or inactivate gossypol while degrading protein quality as little as possible - during the process, it should not exceed 121° C (250° F).

The solvents must be free of chlorine and must be consistent with the list of solvents permitted in the food industry. Lubricants also should be free from chlorine products.

Sodium proponiate may be used as fungal inhibitor only if the residual content in the flour is less than 0.3 per cent.

The standards for flour composition are as follows:

Water	Maximum 10% of flour weight
Oil	Maximum 6% of flour weight
Free fatty acids	Maximum 1.8% of oil weight
Proteins (N x 6.25)	Minimum 50% of flour weight
Soluble proteins 14/	Minimum 65% of protein weight
Total gossypol	Maximum 1.2%
Free gossypol	Maximum 0.06%
Available lysine	Minimum 3.6% of protein weight

Other recommended characteristics are:

- No odour of mould or solvent;
- Under 20,000 bacteria per gram, and no pathogenic varieties (E. Coli, salmonellas, etc.);
- No insects or fragments of insect, no rodent hair or excrement;
- Maximum 0.1 per cent extraneous minerals (sand, mud, etc.);
- Under 0.03 ppm (30 mg/kg) aflatoxin;
- The flour should be packed in protective material (multi-ply kraft paper coated with polyethylene, for example).

14/ The soluble protein content provides an indication of the intensity of heat treatment and the loss of nutritional value: the higher the solubility, the lower the intensity and loss.

Available flours

There are few cotton-seed flours on the market, but many experimental and commercial trials have been made which show that the industrial production of flours meeting the above standards is possible, provided the precautions mentioned earlier are taken.

It is easier to produce acceptable flour by solvent extraction, with or without pre-pressing, than by screw-press extraction, but production is possible even with the latter process.

Examination of the various points of the standard shows the following:

There is no difficulty in maintaining the moisture content under 10 per cent. The average is 7-9 per cent;

The 6 per cent maximum oil content is justified by the need to avoid rancidity. Screw presses produce flour containing about 4 per cent oil; solvent processes reduce the oil content to 1 per cent;

The protein content varies according to the seed variety and the residual percentage of hull scrap. It often exceeds 50 per cent and may be as much as 65 per cent;

The limit for total gossypol content seems to be rather high, but once the linters, hull and oil are removed, the kernel usually contains 0.7-1.5 per cent gossypol; so not all processes are suitable. Glandless seeds are clearly the best raw material;

The limit of 0.06 per cent for free gossypol is essential, because it is a protection against toxicity;

The lysine content required implies oil extraction by solvent.

The best cotton-seed flours, from traditional or, better still, glandless seeds, are light in colour, have hardly any odour, and meet the PAG requirements. They contain 2-4 per cent of raw fibre, 6-10 per cent ash - of which the main cations are phosphorus and potassium - and a useful amount of group B vitamins. The other components (glucides, etc.) have not yet been studied fully.

D. Nutritional value of high-quality flour

We shall now compare the amino-acid composition of a high-quality cotton-seed flour (glandless seed and/or solvent oil extraction only) with that of soya flour (also of high quality) and two reference animal proteins: egg-white and casein (table 12).

Table 12. Protein composition[a] of cotton-seed flour compared with that of soya flour, egg-white and casein

Essential and semi-essential amino-acids	Cotton-seed flour b/	Soya flour	Egg-white	Casein (cow's milk)
Arginine	11.2	7.0	6.3	4.1
Cysteine	2.0	1.2	2.5	0.4
Histidine	2.7	2.8	2.7	3.1
Isoleucine	3.9	4.7	7.2	5.8
Leucine	6.1	7.9	8.5	9.2
Lysine	4.2	6.3	7.0	7.6
Methionine	1.5	1.3	4.1	2.8
Phenylalanine	5.2	5.3	6.1	5.4
Threonine	3.4	3.9	5.2	4.5
Tryptophan	1.4	1.3	2.0	1.3
Tyrosine	3.2	3.8	4.6	5.7
Valine	4.9	5.0	8.8	7.1

a/ Weight in 100 g of proteins - N x 6.25.

b/ Values indicated by Bailey, 1948.

It can be seen that cotton-seed proteins contain less lysine than the two animal proteins and also than soya flour. However, they contain more lysine than cereal proteins, for which the average lysine content is as follows (in percentages):

Wheat	Barley	Oats	Rye	Maize	Rice	Sorghum
2.3	3.5	3.7	2.9	2.9	4.1	1.6

Cotton-seed proteins are also deficient in methionine (like soya flour, in which methionine is the first limiting factor), isoleucine and threonine.

Many authors have studied laboratory or farm animals, and also man, to establish the nutritional value of cotton-seed flour supplemented with certain amino-acids (mainly lysine and methionine) or mixed with other proteins (soya or cereal, for example).

The studies show that the nutritional value of cotton-seed flour is lower than that of soya flour, but adding lysine or mixing with soya flour produces a product that is generally satisfactory for infant feeding.

Everything depends, in fact, upon the grounds chosen for comparison: there is no doubt that milk proteins are the best, but many tropical countries do not produce enough milk proteins and cannot afford to buy them. If those countries grow cotton, they may have an additional source of proteins that considerably increases the nutritional value of cereal flour.

The foregoing is illustrated by three examples of applications.

Inclusion in bread

Much research has been done on this subject (Rooney *et al.* (1972), Matthews *et al.* (1970), Tsen *et al.* (1971), Harden and Yank (1975)). Harden and Yank replaced 18.8 per cent of wheat flour by cotton-seed flour of two different origins - glandless seeds and LCP seeds. The resulting bread contained 20 per cent protein compared with 10 per cent for ordinary bread. (The water content of bread is 20-26 per cent by weight). The enriched bread was very similar to whole-meal bread in its dark colour, its rough and compact texture, and high density. It produced a faster weight increase in young rats than ordinary bread.

Improvement of sorghum flour

Sorghum, which is the third most important of world cereal resources, after wheat and rice, contains proteins of low nutritional value because of the lack of lysine: Pomeranz (1966) and Bookwalter (1971) showed that the addition of soya flour improved both the quality and quantity of the proteins; Bookwalter, Warner and Anderson (1977) subsequently tried the addition of cotton-seed flour and produced a satisfactory increase in nutritive value, albeit a lower one than that produced by soya flour.

Inclusion in millet pap

French workers at ORSTOM (Office de la recherche scientifique et technique d'outre-mer) studied in Chad the physiological effect of adding cotton-seed flour to millet pap fed to babies. It appeared that the mixture was accepted, well tolerated, and produced better growth.

A great deal of other work has been done in various countries (by INCAP in Central and South America, for example), but to describe it would add little useful information for this global survey.

E. Protein isolates

When the protein content of flour is increased to over 90 per cent an isolate is obtained.

The usual extraction process consists in washing the flour with water so as to remove soluble matter, dissolving the residue in an alkaline medium (with the help of soda), and precipitating the isolate by acidification.

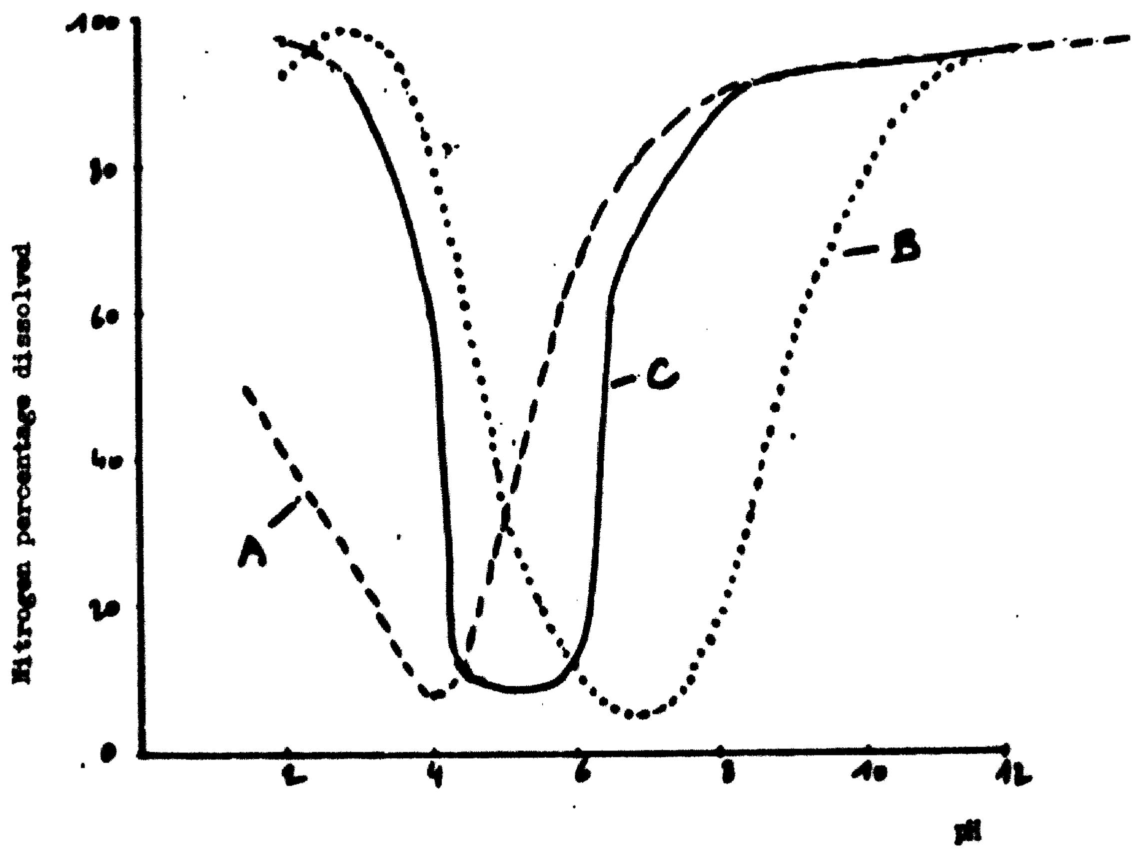
The properties of the isolate depend on the processes used, as various studies on the subject have shown.

From 1969, Berardi et al. demonstrated that cotton-seed proteins consisted of two fractions: a water-soluble fraction that precipitates at pH 4, and represents 30 per cent of the total nitrogen, and a water-insoluble fraction, which becomes soluble in an alkaline medium ($pH > 9$), and can then be precipitated at pH 7, representing 60 per cent of the total nitrogen.

Figure II shows the curves of solubility as a function of pH for each fraction and for the two fractions together.

The distinction is important, because the soluble proteins of low molecular weight have a far higher nutritive value than the insoluble proteins, owing to their higher lysine and sulphurous amino-acid content (as table 13 shows). On the other hand, the insoluble fraction, which is derived from the seed's reserve proteins, is a good functional additive, especially in bread-manufacturing, where it hardly changes colour and texture, but has the unusual property of dissolving in an acid medium, which makes it possible to include it in acidified drinks.

Figure II. Cotton-seed protein solubility
as a function of pH



Legend: A = soluble fraction
B = insoluble fraction
C = both fractions

Table 13. Aminograms of the two protein fractions of cotton-seed

Essential and semi-essential amino-acids	Soluble proteins	Insoluble proteins
Arginine	10.4	11.3
Cysteine	2.6	0.3
Histidine	2.6	3.0
Isoleucine	2.6	3.1
Leucine	5.1	5.8
Lysine	6.0	3.0
Methionine	1.7	1.0
Phenylalanine	3.7	6.3
Threonine	2.9	2.7
Tryptophan	?	?
Tyrosine	3.3	2.6
Valine	3.3	4.4

Source: Martinez et al., 1970

Table 13 shows that the soluble fraction contains almost as much lysine as soya flour and more sulphurous amino-acids (methionine/cysteine). Its protein efficiency ratio reaches 2.3. The authors describe the extraction process as follows:

> If a single step is used, the proteins are dissolved in a diluted soda solution (pH 9.85); precipitation at pH 5 then produces a mixture of the two fractions.
>
> If the fractions are to be separated, however, two steps are required. First, the soluble proteins are dissolved in water (pH 6.7) and precipitated at pH 4. The insoluble fraction is made soluble by adding soda (pH 9.8) and precipitated at pH 7. The insoluble proteins can also be precipitated at pH 3 by using their ability to form insoluble compounds with calcium ions: an acid and calcium chlorate are added.

Cotton-seed isolates usually contain 93-98 per cent protein, calculated by the Kjeldahl method. When the seed used is a glandless variety, the colour is light - although darker than soya or groundnut isolates - and the flavour slight.

F. The use of cotton-seed protein in food for human consumption

Although there is a market for cotton-seed flour, few firms are interested in it. In the United States, several varieties with a protein content of 55-65 per cent are sold for use in bakeries. In Italy, flour obtained by the Vaccarino process is sold on the home market and to some extent abroad.

The Nutrition Institute of Panama and Central America (INCAP) has also been studying, for some twenty years, various mixtures containing cotton-seed flour, called Incaparina. Several formulae have been prepared under that name for mixtures of cereal flours (rice, maize, sorghum, corn, and others) with cotton-seed flour, soya flour or both (table 14).

Table 14. Incaparina formulae

Components in g/100 g	Three Incaparina formulae		
	No. 9	No. 14	No. 15
Pre-cooked cereal flour	58	58	58
Protein concentrates:			
Cotton-seed concentrate	38	-	19
Soya concentrate	-	38	19
Additives:			
Torula yeast	3	3	3
Calcium carbonate	1	1	1
TOTAL AMOUNT	100	100	100

Source: FAO.

The protein content ranges from 25 to 28 per cent.

INCAP does not manufacture Incaparina, but licenses the formulae to companies.

General practical characteristics

Cotton-seed flours, concentrates and isolates[15] may be used for nutritive purposes, functional purposes (improvement of food texture, appearance, conservation, etc.) or both.

15/ Though the flours are themselves protein concentrates, the term is usually applied to flours that contain more than 50 per cent protein - which means in practice 50-70 per cent.

The nutritive value has already been indicated.

As far as the functional properties are concerned, it will be noted that cotton-seed proteins:

Retain water (cotton-seed concentrate absorbs 2.5 times its weight of water) but less so than soya (soya concentrates and isolates absorb five to six times their weight of water) or groundnut proteins;

Are less soluble than soya proteins: solubility depends, of course on the pH, and is different for each fraction;

Are consequently somewhat viscous and may produce gels (as a result of their water retaining and solubility properties), but to a lesser extent than soya proteins;

Absorb oils to almost the same extent as soya proteins (the concentrate retains 1.5 times its weight of oil);

Emulsify fats better than soya proteins, which is a potential advantage in meat preparations such as sausage fillings.

It is difficult to obtain a very light colour. The flavour is fairly neutral. The residual lipids, which oxidize in storage, are responsible for rancidity and a dark colouring; the quantity present should be as small as possible.

Applications

Baking, biscuit-making and pastry-making

The American Institute of Baking has made a series of trials for including cotton-seed concentrates and isolates in bread to replace cornflour and/or skimmed milk powder. Added in amounts of 3 per cent, 2.6 per cent and 1.6 per cent respectively, cotton-seed flours, concentrates and isolates gave results equal to those of 3 per cent skimmed milk powder, provided the kneading time was reduced. Higher substitution levels around 10 per cent also produced acceptable bread with flour and concentrates, but with bromate added. With cotton-seed isolates, however, 10 and even 15 per cent added, without bromate, gave a good bakery-quality bread.

Some United States bakeries add very small quantities of cotton-seed proteins for functional purposes (to retain water and improve the crust colour, for instance) as a substitute for skimmed milk powder. For such uses, the nutritional value is irrelevant.

Soviet research workers have made similar studies.

Cotton-seed proteins can be added to dough products other than bread. Tests have been made with:

Biscuits, which have as a result a protein content of 10-18 per cent;

Doughnuts, to use the ability of protein in general, and cotton-seed protein in particular, to fix fats;

Snack foods and breakfast cereals.

In such products, up to 20 per cent of cotton-seed protein concentrate can be used as a substitute for cornflour.

Other cereal products

Incaparina can be consumed in colada, a fine gruel much liked in South America, in cakes, soups, etc., and in the drink known as atole.

In Israel, a cotton-seed concentrate and cornflour mixture that contains 35 per cent protein is used as a baby food after sugar and water have been added.

In Chad and Cameroon, ORSTOM has tested rissoles, paps, doughnuts, noodles and sauces that use cotton-seed flour as an additive to local cereals (particularly sorghum).

In certain other countries, such as India, Pakistan, and Peru, formulation tests have been made for baby-food flours containing cotton-seed proteins. The work does not seem to have gone much beyond the laboratory stage.

Meat products

Cotton-seed protein has poorer gelifying properties than soya-bean protein, but its emulsifying properties are better. Its functional usefulness depends on the application.

It can be easily texturised by original techniques which are neither extrusion nor drawing: in a single-step operation, with heating to 80°-90° C, pH adjustment and thorough agitation, mixtures of cotton-seed proteins + lipids + carbohydrates + flavours can be obtained whose consistency is like that of meat.

Extrusion is also possible and is being studied.

Other products

The fact that reserve proteins, which represent the main fraction, are soluble in an acid medium has prompted some research workers to use them, at a maximum level of 6 per cent, in fruit drinks. However, the low nutritive value of the fraction and the small amounts used make the addition rather uninteresting.

Cotton-seed protein is sometimes used in confectionery as a moisture-retaining agent.

G. Conclusions

Less than 10,000 tons of cotton-seed flour is used for human consumption throughout the world each year. This is very little, especially in view of the size of the protein shortfall in many countries that grow cotton.

The obstacles are technical and economic, and also psychological.

First, for cotton-seed flour to be acceptable for human consumption, it must, as has been seen, meet requirements that it is not always easy to comply with. For instance, the proper available lysine content can be obtained only if the oil is solvent-extracted, although in many countries only mechanical means (screw or hydraulic presses) are used. The machinery must therefore be changed. Glandless seeds may in time improve the situation, but they are not yet widely grown.

Second, cotton-seed flour must be competitive with soya flour, which is produced industrially on a far larger scale and has a higher nutritive value. This has already been seen with the cakes: the price of cotton-seed cake with 45-46 per cent protein is lower than the price of soya cake with 44 per cent protein; the difference between them varies but is often about 10 per cent. The price of flour must also show an advantage for cotton, but the processes required by the PAG regulations are expensive, especially when the seeds used are not glandless.

Cotton-seed flour will therefore not replace soya flour to an appreciable extent until glandless seeds are produced in sufficient quantity, and the following conditions are met.

If used as a functional additive in rich countries like the United States, cotton-seed flour must offer industrial users considerable savings, which does not seem to be the case today. If the price is the same as or shortly below that of soya flour, users will prefer the latter, by habit and for its better functional properties for most applications.

If it is used as a nutritive supplement in cotton-producing countries where some sectors of the population are short of proteins, the local Governments will have to supply financial help, to an extent to be calculated case by case.

IV. METHODS FOR COTTON-SEED OIL AND CAKE RECOVERY

A. Storage, cleaning and delinting of cotton-seed

Storage

What was said in chapter II about the risks of deterioration of seed cotton, and the ways of avoiding them, also applies to cotton-seed and need not be repeated here.

The optimum moisture content during ginning is 7 per cent. When seed is stored for a long time, the moisture content should remain at this level, or even slightly lower. Since mills receive consignments of varying quality, some even containing deteriorating seed, the moisture content and temperature must be constantly checked.

A temperature above 35° C indicates imminent overheating, and the barn or silo must then be ventilated.[16] Some millers make it a practice to ventilate all the seed received and keep the temperature between 15° and 20° C.

If the seed is damp, it is sometimes dried by hot air insufflation so as to inactivate the lipolytic enzymes. Where this is done, it is advisable to cool the seed afterwards, to reduce the temperature to near ambient.

Cotton-seeds, especially those covered with thick linters, are difficult to handle, and do not flow easily. Suitable handling devices must therefore be provided. Pneumatic systems have the advantage that they cool and aerate the seed, and even dry it to some extent, but mechanical systems are also used.

Cleaning

In some countries, including the United States, the mechanical gathering of seed cotton has increased the amount of extraneous scrap that remains attached to the seed - or rather to the linters - after ginning: the proportion of scrap is now 1-4 per cent of the total seed weight. The impurities include stones, earth, sand, capsule fragments, vegetable scraps of various kinds and metallic particles. Vegetable material tends to decompose when the moisture content is high, and this raises the temperature of the seed. Mineral matter wears the delinters and dehullers prematurely and

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16/ In countries with a dry climate, the seed can be stored in heaps outside, under canvas or uncovered, on concrete areas fitted with airing pipes.

can cause sparks that may produce fires. Finally, and most importantly, high-quality lint and cakes cannot be obtained unless all the undesirable substances are removed.

The amount of waste left in ginning (see chapter II.C.) depends on the method used.

The seed can be pre-cleaned before storage, but the effectiveness of the operation is limited, since very large deliveries are made to the mill over a short period, and there is no time to do the job properly. In practice, some of the sand can be removed easily by, for example, boring small holes in the feed pipes. Boll reels may also be used: these are rotating drums fitted with screens of a mesh that passes the seed and objects of similar size but retains bigger particles (especially seeds that still have their lint). Sand reels are similar: they have fine-mesh screens that pass sand only. Boll reels and sand reels are often set up together, the former above the latter on a common frame. Efficiency is improved by pneumatic seed cleaners. They consist of two (or four) vibrating screens, fed with a carefully metered quantity of seed that has already been passed under an electro-magnet, to remove metallic particles. The upper screen removes the larger impurities, and the lower screen the smaller ones. Screening is assisted by forced draught, and capacity, depending on the type, ranges from 25 to 120 tons per 24 hours.

The oil millers often have to re-clean the seed that comes from the ginning mills. For economic reasons, it is in any case better to clean the seeds in the oil mills rather than ginning mills, since the latter are widely scattered, far more numerous and work for a shorter period during the year.

Besides boll and sand reels and pneumatic cleaners, basket cleaners can be used at the delinter input, or more recent machines known as ARS differentiators or cleaning belts which are based upon the different kinetic principles obeyed by normal seeds, abnormal seeds and impurities when projected.

Only some 50 per cent of extraneous matter can be removed by boll and sand reels, and 55-60 per cent by pneumatic cleaners; ARS removes up to 65 per cent.

<u>Delinting</u>

Delinting consists in taking off the linters - if any - from the seed: seed of the <u>G. barbadense</u> species has no linters.

The average linter content is indicated in chapter I. In the United States, the linters of G. hirsutum account for about 10 per cent of the seed weight.

Delinting is not always economically justified, since the machinery is expensive and a market has to be found for the linters. In Africa, for example, where there is no market,[17] the new mills prefer to forego delinting, thus saving the investment and energy costs, and to dehull the seed with its linters directly. This point will be taken up again in connexion with dehulling.

The traditional method of delinting uses saw devices, known as "delinters", which are similar to saw-gins (cf. chapter II.C.). About 2.5 per cent of the linters are left on the seed to facilitate the subsequent separation of the hull from the kernel. More than 4 per cent linters would cause difficulties in hulling with present machinery.

Saw-delinting

Saw delinters work on the same principle as saw-gins. Since linters are shorter than lint, however, the blades are closer, the feeders are modified so as to present the seeds correctly to the teeth, and in general all the parts must be more precise. Most modern delinters have 141 or 176 circular saws, of 12 5/8 inches diameter (32 cm), which are sharpened at regular intervals (every 8-36 hours). The speed of rotation is about 400 rpm. The machine removes 400 kg of linters from 15 tons of seed in 24 hours. Delinting is usually carried out in a series of steps by successive runs through several delinters. The parameters of each pass - and consequently the qualitative and quantitative yields - may be freely chosen by the millers according to the results required.

The following types of linters can be distinguished:

- Mill-run linters, which are obtained by a single delinting operation, and comprise all linters that could have been removed by two-step delinting;
- First-cut linters, obtained from the first mill run, usually 2-6 mm long, and sometimes longer;
- Second-cut linters, obtained from the second mill run, usually 1-3 mm long.

17/ There is no local market, and it is unprofitable to transport linters over long distances.

Three and even four runs may be made.

If two runs are to suffice, one delinter will take off 400 kg of linters from 15 tons of seed in 24 hours in the first run. The second run will require two delinters, each of which will take off 450 kg of linters in 24 hours from 7.5 tons of seed in the second run.

The second-cut delinters rotate faster (600-750 rpm).

In 1965, a high capacity delinter appeared (the Carver Cotton Gin Co. HC 2). Its saws are larger in diameter (18 inches, 45.7 cm), the capacity of the unit is higher, and so is the speed of rotation. Performance is better: in a single mill run, it can process about 10 tons of seed every 24 hours, leaving only 2.5 per cent linters; in a two run operation, the first run can process 25 tons every 24 hours, leaving 7.3 per cent linters; the second run processes 12-18 tons every 24 hours.

Other methods

Saw-delinting uses a lot of power, requires expensive and delicate plant, and produces a great deal of dust and noise.

It can be done away with completely, however, or replaced by other methods:

- Linter burning requires a very strict control of temperature so as to avoid damage to the seed.
- Acid delinting (using hydrochloric or sulphuric acid) has been tried, but the acid must be neutralised afterwards with a base (gaseous ammonia). The effect on the nutritive quality of the seed and the corrosion of plant must be studied carefully.
- Abrasive delinting uses more power than saw-delinting, produces just as much noise and dust, and requires substantial investment.

Linter cleaning

On leaving the delinters, the linters still contain impurities that must be removed if good merchant quality is wanted. The users need cellulose that is as pure as possible, particularly for the more refined uses.

In modern oil mills, each bank of delinters is fitted with a pneumatic cleaning device that sucks the linters into a condenser where some of the dust is removed. The cleaning itself is done subsequently in multiple-drum beaters fitted with an air system. The cleaners have several large chambers in which the linters are thrown against the perforated surfaces through which the smaller impurities, especially hull dust, can pass.

First-cut and second-cut linters may be cleaned separately.

B. Dehulling and hull separation

Dehulling consists in breaking the hull so as to release the kernel, from which the hull scraps then have to be removed.

Dehulling is not used everywhere. It nevertheless seems justified, since the hull contains very little oil and protein, and a lot of cellulose (see chapter I.F.). Keeping the hull would therefore reduce oil recovery rates (the hull scraps would absorb oil during pressing) and cake protein content, while increasing cake cellulose, lignin and other substances. The crude oil would also be darker in colour.

There are two categories of dehuller: bar hullers and disc hullers.

Bar hullers have two main components: a rotating drum and a fixed frame, both bearing fixed hard steel blades with perfectly sharpened teeth and adjustable clearance. The speed of rotation varies from 650 to 950 rpm. The amount of seed that can be processed in 24 hours depends on the size of the machine and the degree of dehulling required: it varies from 75 to 150 tons for 80-85 per cent dehulled seeds, the remainder being processed a second time.

Disc hullers, which are less common than bar hullers, consist of two sharp-edged circular discs, one fixed and one movable. The inner faces of the discs are concave so that seed can be fed in at the centre. The seed is swept by centrifugal force through the narrowing gap to the periphery where it is cut by the sharp edges, whose clearance is adjustable.

Seed beaters are located before the dehullers to remove certain impurities (linters etc.). After dehulling, the kernels are separated from the hulls. This operation is essential, since it governs the composition of the hull scraps, which must take with them a minimum of oil, kernels and whole seed, and the composition of the kernels, which must be free of linters and dust and must contain only as much hull as is consistent with the cake protein content decided on.

The factors that have to be taken into account are the seed moisture content and degree of deterioration, the percentage of residual linters, the quantity of oil absorbed by the hull before dehulling and separation, the amount of impurities, and the separating plant and its adjustment.

The hulls discarded by a modern mill supplied with high-quality seed containing 10-12 per cent moisture and less than 2.5 per cent linters retain a negligible percentage of oil (0.5 per cent).

There are three different dehulling processes:

Single dehulling and separation

In single dehulling and separation, one machine dehulls 80-85 per cent of the seed in one run. The kernels are separated by a shaker-screen, while the hulls and the remaining whole seeds are processed again in a beater and then in a special machine that recovers the undehulled seeds, which are returned to the dehuller. The plant also has a kernel cleaner that removes hulls and linters.

Double dehulling and separation

In double dehulling and separation, two groups of dehullers and separators are used. The first dehuller is adjusted to produce the largest kernel fragments possible, and thus avoid any absorption of oil by the hulls. The undehulled seeds are conveyed with the hull and kernel mixture to the screen separator, where the kernels pass through the holes. The hulls and whole seeds are channelled to the beater, where the particles of kernel still adhering to the hulls are recovered. The seeds and hulls are then conveyed to the second group of machines where the operation is repeated (with a closer setting of the blades). This method requires more investment than the first and leaves more specks of hull in the kernels, and more oil in the hulls. This lowers cake quality (for non-ruminants at least) and oil yield. It is used mainly when the linters have not been removed from the seed first, or when there are many unripe seeds.

Universal dehulling and separation

The universal method is a combination of the other two. The hulls from the first separator pass into the second dehuller, with a closer setting, and then into a second bank of separator-beaters. The method is useful when the seed being processed still has its linters, and the intention is to leave a large percentage of hull specks in the meal so as to produce cake with a low protein content.

It is accepted that under normal extraction conditions, about 94 per cent of the seed nitrogen finishes up in the cake.

The main points to be watched during dehulling are: that the machine receives a steady feed, and that the blades are correctly set and maintained.

Some machines combine the functions of separation, beating and cleaning.

Defibrators are sometimes used to recover the linters remaining on the hulls: in the United States, some 60 per cent of those linters are recovered, or 1.2-1.5 per cent of the original seed weight. A defibrator can process 10-12 tons of hulls every 24 hours.

The dehulling of undelinted seeds covered with thick linters raises technical problems: the feed rate must be slower, the proportion of oil and kernels removed with the lintered hulls is higher, and separation becomes difficult because of separator jamming. A reduced flow must therefore be accepted, and the plant must be adapted to prevent the hulls carrying away too much oil and meal. The problem has been studied in the United States by S. P. Clark (Texas, A and M University), and in France by Speichim. It will be noted that the linters agglomerate the hull scraps; so the kernels are practically free of them. This is an advantage for flour intended for human consumption, but it complicates the work of the presses in the oil mills and is unnecessary for the manufacture of cake.

Calculations made in the United States by S. P. Clark in 1976 show that if the oil millers' selling price[18/] of linters is 4 cents a pound (8.8 cents a kilogram) or over, it is better to delint before dehulling, but below 3 cents a pound (6.6 cents a kilogram) the seed can be dehulled without delinting, or after delinting with acid.

18/ Weighted average of first and second cuts.

C. Rolling of kernels into flakes

After dehulling and separation, the kernels are vulnerable to mould, and even when the moisture content is low (7 per cent) they keep for a very short time; acidification is likely to occur within a few days. It is thus advisable to process the kernels as soon as possible.

The kernels must be flaked to break down the walls of some of the cells containing oil, and mainly to divide the material finely so as to expose it as much as possible to heat and steam during the subsequent cooking, and thus facilitate oil extraction.

The kernels must first be moistened to bring their moisture content up to 10-11 per cent.

The kernels are usually flaked in a machine consisting of five carefully aligned, superimposed cylinders made of hardened cast iron. Sometimes only two horizontal cylinders are used, but the capacity is then lower.

A feeder, whose output is carefully metered, distributes meal uniformly along the top cylinder; the kernels are then drawn in between the first and second cylinders and finally between the fourth and fifth, where they carry the weight of the four upper cylinders.

The diameter of the cylinders ranges from 12 to 20 inches (30.5 to 51 cm), and the length from 24 to 60 inches (61 to 152 cm). The meal input cannot exceed the equivalent of 1.5 tons of seed every 24 hours per inch of length.

The flakes must be as thin as possible. A thickness down to 0.005 inches (0.127 mm) may be reached, but is usually from 0.008 to 0.013 inches (0.203 to 0.330 mm).

The main points to watch are the proportion of undehulled seed and residual hull, the steadiness of the feed to the unit, and the condition of the cylinder surfaces.

D. Cooking of the flakes

There are several reasons for cooking:

- To complete the breakdown of the oil cell walls;
- To increase oil fluidity by increasing the temperature;
- To coagulate and precipitate the proteins, which facilitates oil extraction;
- To coagulate and precipitate the phosphatides;
- To change pectic material into mucilaginous substances that are insoluble in oil;
- To detoxify the gossypol by binding it to proteins;
- To destroy moulds, bacteria and enzymes that could affect the oil and cake adversely (by helping the development of free fatty acids);
- To dry the meal to a moisture content to suit the oil extraction operation.

The cooking and final drying of the meal may be done in various kinds of equipment, the more common of which consist of four to six (sometimes up to 10) stacked boilers with double walls between which steam is passed, and agitators to churn the meal. Since cotton-seed meal is a poor conductor of heat, the agitators must be powerful. The flakes are put into the top boiler, where hot water or steam is added to increase the moisture content to 11-14 per cent. They are then conveyed down from boiler to boiler with a corresponding rise in temperature.

The oil yield and colour and the nutritive value and flavour of the cake depend to a large extent on the way the meal is cooked. The variables are the amount of water added, the temperature of each boiler, the cooking time in each boiler, and the agitation speeds. The variables are adjusted according to the characteristics of the raw material and the desired characteristics of the end product. The oil extraction technique to be used is of particular importance.

Since one of the main aims is to inactivate the gossypol without degrading protein quality too much (cf. chapter III.A.), a compromise must be found between too little and too much heat.

In addition, a temperature of 88° C (190° F) must be reached quickly, since below that temperature enzymes in the presence of water are very active, and could cause undesirable hydrolysis or lipolysis (production of fatty acids).

In a five-boiler cooker, the temperatures would in practice be as follows:

Boiler	° C	° F
1	79 - 90	175 - 195
2	82 - 96	180 - 205
3	93 - 102	200 - 215
4	102 - 107	215 - 225
5	107 - 113	225 - 235

In the first boiler, the temperature must be brought up to 88° C within about 20 minutes.

The total cooking time depends on the subsequent oil-extraction process: 80-120 minutes when hydraulic presses are used, 75-85 minutes with screw presses, and 30-40 minutes with solvent after pre-pressing.

The water content of the meal decreases steadily from the first boiler to the last. Its optimum at the output is 5.5-7 per cent for hydraulic press extraction, 3-6 per cent for screw-press extraction, and 4-5 per cent for hexane-extraction.

The capacity of such a cooker is 125-150 tons of seed every 24 hours.

When the cooker works at normal production capacity, the cake contains less than 4.2 per cent oil after passing through the screw press. When the cooker works beyond capacity, the residual oil content rises. There is thus no point in trying to exceed capacity.

Other types of cooker include horizontal cooker-driers, where cooking and drying take place in separate compartments.

E. Oil extraction[19]

Hydraulic-press extraction

Hydraulic-press extraction is an obsolete process, but is still used in some countries. It consists of an initial moulding, after which the meal passes into a hydraulic plate press (usually with 15 plates). If the operation is

19/ For the technical descriptions of oil extraction and processing, specialist works should be consulted - K. Murti and K. Achaya, 1975, for example.

correctly regulated, the cake is progressively drained, the oil contains few impurities, and the press cloth does not wear out prematurely. The average pressing cycle is about 30 minutes, but may be as long as 45. With a 30 minute cycle, the extraction capacity is the equivalent of 15 tons of seed every 24 hours, and the residual oil content of the cake is 5.5-6.5 per cent.

The cake can then be sold either as it is, or broken into pieces or ground into meal by disc- or hammer-mills and screened. Sometimes the flour is moistened, heated and pressed into small cubes.

The advantages of the hydraulic press over the screw press are: the investment and power consumption are lower, and the oil is lighter in colour and contains less free gossypol. The advantages do not outweigh the disadvantages, however: the labour cost is higher, the equipment cannot be easily adapted, the oil yield is lower, and there is more free gossypol in the cake. Above all, the screw press can easily be used for processing other seeds than cotton-seed. For these reasons, hydraulic pressing is increasingly giving way to screw-pressing.

Screw-pressing

Screw presses work continuously.

Many different types of screw press have been built since the first one built by Anderson at the beginning of the century.

Their capacity depends on the number of shafts, the section and particularly the speed of rotation. It varies from 6 to 100 tons equivalent of cotton-seed processed in 24 hours, and sometimes is even more, but is usually about 50 tons. Output increases with increasing speed of rotation, but the cake oil content also rises to as much as 9-15 per cent.

With a properly adjusted unit rotating at normal speed (about 45 rpm), the cake contains less than 3.5-4.5 per cent oil.

When only a pre-pressing prior to solvent extraction is required, capacity is increased to 100 tons of processed seed every 24 hours, with a cake-oil content of 10 per cent.

The absorbed energy is partially converted into heat, and the meal reaches a temperature of 150° C (300° F). The heat, together with the considerable pressure in the press, degrades protein quality (cf. chapter III.A. and B.)

darkens the colour of the oil, and increases the level of impurities in the oil. Cooling is therefore required, and this is done by various means, the most common of which is a heat exchanger.

On leaving the press, the cake is too dry (1-4 per cent water) and too hot. It is cooled and simultaneously moistened by a stream of cold water. It is also ventilated. The last step is grinding in a hammer or double rotating disc mill; the former consumes less power but produces a coarser granulated product.

An average cake contains 3.5-4.5 per cent oil, 41-43 per cent proteins, 8 per cent water, and 0.04 per cent free gossypol. The available lysine content of the proteins is only 2.5-3 per cent (cf. chapter III.A.).

The crude oil contains insoluble impurities ("feet") and free fatty acids (average 1.2 per cent). About 8.5 per cent of the oil will be lost in refining. The impurities are removed by decanting or screening followed by clarification by filter press. The oil should be at a temperature of about 55° C during these operations. Once separated from the oil, the impurities are recycled in a special screw press or in the production press. In the latter case, the cooking step must be omitted; otherwise the oil will be dark.

The free fatty acid content of the oil depends on the condition of the seed used. If the seeds are already very acid on delivery, cooking and pressing (both of which increase acidity by about 70 per cent) will have to be carefully monitored. In particular, the flakes must have a moisture content of at least 12 per cent before cooking, and the cooking time must be longer than usual. Acid seed often produces a high proportion of impurities.

The free fatty acid content of the oil is often as high as 2 per cent.

The last oil fractions are usually more acid than the first; if extraction is taken too far, the results of refining will be less satisfactory.

The ease with which the gums, or more exactly the pectic substances from the material lying between the cell membranes, pass into the oil increases with moisture content. Since the gums delay the deposition of soap stock, they hinder the refining process, and are therefore often responsible for bad yields at this stage.

The gossypol content of the oil varies from 0.3 to 1 per cent according to the raw material and processing. During neutralization, which is a refining step, gossypol combines with soda and passes into the soap stock.

In some countries (India for example), undelinted and undehulled seeds are screw-pressed. The oil yield is lower, the oil and cake are of inferior quality, and the press capacity is reduced, but the simplicity of the process makes it cheap.

Dehulled seeds are also sometimes pressed without prior delinting. The oil and cake are of satisfactory quality, but some of the oil (4 per cent) is lost.

An original oil extraction process, called the Skipin process after its inventor, is used in the USSR. It consists of three operations. The meal is first moistened to bring the water content up to 14.5-20 per cent and heated to 70° C, which separates the oil from the meal. The oil drains through a screen to the bottom of the device, where it is collected. The partially de-oiled cake is then dried to reduce the moisture content to the level required for solvent extraction. All the gossypol is found in the oil.

Solvent extraction

Solvent extraction can be applied to:

- Undehulled, and even undelinted cotton-seed;
- Dehulled cotton-seed;
- Pre-(screw-)pressed partially de-oiled cake (pre-press solvent extraction).

The main advantage of solvent extraction over the mechanical processes reviewed above is that it improves the oil yield, since the residual oil content of the cake does not exceed 0.5-2 per cent. Moreover, since the material is heated less, the proteins have a higher nutritional value (cf. chapter III.A. and B.).

There are, however, some disadvantages:

- Solvent extraction demands greater investment and is therefore suitable only where large tonnages are to be processed;
- Inflammable solvents, particularly the hydrocarbon derivatives (hexane), may cause a risk of fire and explosion on mixture with air;

- The cake tends to be dusty;
- If the meal is insufficiently cooked, there may be free gossypol in the cake.

The direct solvent extraction of oil from dehulled seeds is also rather difficult: the material disintegrates readily, and small particles may get mixed with the miscellae (see definition below), and steps must be taken to avoid or rectify this. If undehulled seeds are used, extraction is easier, but the oil obtained is darker and the cake of poorer quality.

Pre-press solvent extraction gives a slightly higher oil yield than direct extraction and seems to be preferred nowadays.

The process will not be described in detail here but the principles involved can be resumed as follows:

Principles of solvent extraction

The meal and the solvent must come into the most intimate contact possible. This requires a large volume of solvent at a suitable temperature (50-65° C), meal with a suitable moisture content (which varies according to the equipment) and a satisfactory degree of granulation, and a long mixing of meal and solvent.

When batch extractors are used, several should be used in series. When continuous extractors are used, the meal and the solvent are made to circulate in counter-current (less favoured nowadays) or parallel. In the filtration-extraction process, the meal and the miscella are first kept for a while in a mixer, before they are separated by a horizontal continuous rotary vacuum filter.

The result is a solution of oil in solvent, known as a miscella, the concentration of which varies according to the solvent used and the oil content of the meal. In modern continuous units, the miscellae contain 20-25 per cent oil, and sometimes more. The older continuous units and the batch extractors produce miscellae with a much lower oil content.

The miscellae are filtered so as to remove the particles of cake, concentrated, and distilled in a single or double evaporator. They then pass into a stripping column, usually under partial vacuum, with steam injection for total solvent removal. The vapours are condensed in standard water condensers, and the oil is cooled and stored. The condensates are collected in a separator where the water injected as steam is removed from the solvent.

The solvent remaining in the meal must also be recovered by heating in the extractor itself, or in an independent drier. Here, too, the last traces of solvent are driven off by live steam, provided the material permits this. In some units, the process is conducted under vacuum, which allows working at a lower temperature and gentler treatment of the cake. After cooling, the cake is usually crushed.

The uncondensed gases remaining in the apparatus are recovered by connexion to mineral oil columns, activated charcoal absorbers, or a refrigeration installation, or by a combination of these methods.

The cake may be completely freed of solvent or may retain a small amount (0.1 per cent), but there is then a danger of explosion during storage or transport, an unpleasant odour, and a nutritional drawback.

It must be stressed that only a brief outline of the operations has been given, and that the methods are developing rapidly, particularly where solvent recovery is concerned - an area where huge improvements have been made in the last 15 years.

Remarks on operations prior to extraction

Cleaning, delinting, dehulling and hull separation are the same as for mechanical extraction processes. There are some differences, however, in flake rolling and cooking.

In pre-press solvent extraction, the main difference is that cooking may take place at a lower temperature (20° C), the cycle may be shorter, and the final moisture content can be 8-9 per cent. The oil content of the meal is 10-12 per cent. The meal is ground and re-rolled into flakes, and then conveyed to the solvent extractor, which it leaves with an oil content as low as 0.3-0.5 per cent. Direct solvent extraction yields are not as good (residual oil is 1-2 per cent). The cake is less crumbly and the miscellae contain less impurities. The gossypol content of the cake is lower than with direct solvent extraction, but so is the available lysine content.

In direct solvent extraction, the kernels are crushed under rollers, and their moisture content is increased to 10 per cent. The cooking is done at a far lower temperature than in the other processes (50°-80° C), they are rolled into flakes as fine as possible (0.006-0.010 inches, or 0.15-0.25 mm). Direct extraction uses far more solvent than pre-press solvent extraction. The filtration-extraction process, which is a variation of direct extraction, requires cooking at 93-107° C (200-225° F) and 9-20 per cent water in the meal during processing.

Choice of solvent

The most commonly used solvent in the United States is hexane, a paraffinic hydrocarbon derived from petroleum distillation. Its boiling point under normal pressure varies from 63.3° to 69° C, depending on the supplier. Methylpentanes, which have the same origin, boil at a lower temperature (59.4°-63° C) and thus require a lower power consumption. Nevertheless, although they are efficient as cotton-seed oil solvents, they are less used than hexane.

Trichloroethylene has the advantage of being less inflammable than the hydrocarbons. It boils at 87° C under normal pressure, and is an excellent solvent. However, it consumes more energy for distillation than hexane, and produces darker oils that are difficult to bleach, especially if undehulled seed is used. It must also be stabilized before use to prevent acidification and, since its vapour is corrosive, equipment in contact with it must be made of stainless steel or aluminium. There is also some doubt as to the toxicity of the cake, which explains why it is not used in the United States.

Isopropyl alcohol could solve the problem. It completely removes gossypol with the oil. Consequently, there is no free gossypol left in the cake, but it must be removed from the oil by additional processing. It does not seem to have been used in industry.

Ethanol is also a possible solvent. It has been neglected in the United States, where producers find it simpler and cheaper to use paraffinic hydrocarbon petroleum derivatives. In other countries, it might be useful to use ethanol derived from agricultural products so as to reduce the outflow of foreign exchange.

The Vaccarino process employed in Italy uses acetone; and the SRRL process (see chapter II.B.) uses an azeotropic acetone-hexane-water mixture. Both remove almost all the free gossypol from the cake (the SRRL process more than the Vaccarino), but both processes cost more than the hexane process.

A short survey of equipment

As has been seen, extraction may be by batch or continuous. Continuous extraction is the more modern. Continuous extractors fall into two categories:

- Immersion extractors, where the solids are immersed in the solvent;
- Percolation extractors, where the solvent flows through a stationary or moving bed of solids.

For various reasons, percolation is currently the preferred method.

The filtration-extraction technique is a form of percolation, but has its own characteristics.

Capacities, expressed in equivalent tons of cotton-seed processed in 24 hours, are 40-120 tons for the immersion equipment, 100-250 tons for percolation-type equipment,[20] and about 100 tons for filtration-extraction units.

There are also higher capacity extractors (500-2,000 tons/24 hours) designed for mills processing large volumes of seed, which may be of various kinds (cotton, soya, etc.).

In any installation, care must be taken to ensure that the solid and solvent flows are steady.

With modern, properly used equipment, solvent losses are less than 1 per cent by weight of the input material. The losses can be reduced to 0.5 or even 0.3 per cent.

Conclusion

As things stand at present, screw-press extraction and pre-press solvent extraction seem to be the most interesting processes from the economic point of view.

The development of glandless varieties may favour direct solvent extraction in the future.

20/ There are also smaller units of 25-75 tons.

F. Oil refining

Besides triglycerides, crude oil contains varying amounts of other impurities: free fatty acids, water, resins, albuminous material, gums, phosphatides, sterols, pigments, sapid and aromatic substances (particularly ketones and aldehydes), and decomposition products. Some of these are insoluble in the oil; others are in solution or colloidal suspension.

The task of the refiner is to remove all the non-glycerides as completely as possible so as to produce an edible oil of good appearance, or a finished product suitable for the production of edible fats.

The main refining steps will be examined in order. They are:

- Degumming;
- Neutralization;
- Bleaching;
- Deodorization.

Two treatments associated with the processing of refined oil will not be included: hydrogenation, which converts liquid oil into solid or semi-solid fat by the partial or total saturation of the double bonds; and winterization which, in contrast, removes from the oil the high boiling triglycerides, so that the oil stays clear even at low temperatures.[21]

Generally speaking, cotton-seed oil refining is much the same as for other edible oils, except for the tricky problem of gossypol removal. The development of glandless seeds will also simplify this.

Crude oil storage

Before crude oil is stored, it must be freed of such insoluble impurities as fragments of seed, dust, water,[22] etc. If this is not done, the enzymes present could cause lipolysis, which would increase entailing the free fatty acid content. There might also be a proliferation of micro-organisms that would assist lipolysis and cause disagreeable decomposition. The insoluble impurities are removed by decanting, filtration or centrifuging; filtration (by filter press, for example) is the most commonly used method.

21/ Ordinary cotton-seed oil turns cloudy below 5-7° C. After winterisation, it stays clear at 0° C.

22/ Most crude oils contain about 0.5 per cent water.

During storage, the pigments (gossypol and others) may bind irreversibly with the triglycerides. This reaction develops rapidly, and depends on the pigment content and temperature. It is thus advisable to store crude cotton-seed oils, after proper filtration and dehydration, for the shortest possible time, and at the lowest temperature consistent with fluidity.

Degumming

Degumming consists in removing gums, resins, proteins, phosphatides,[23] and other constituents in fine colloidal dispersion. All these will be referred to as "gums". After removal, they are added to the cake, where they increase cohesion and thus improve granulation, or to the soap stock, which will be defined below (chapter VII.C.).

There are several degumming methods. The most traditional is based on hydration, using the gum's property of swelling and forming gels in the presence of a specific amount of water. These gels, of high specific gravity, precipitate on the bottom of the oil recipient. A small quantity of water - 2-5 per cent of the oil weight - is injected, the temperature is kept at 60-90° C, depending on the method, and the gums are separated by centrifuging. As the degummed oil still contains 0.4-0.8 per cent water, it is conveyed to a drier where it is heated to about 70° C under a slight vacuum. It is then cooled and stored. This dehydration phase is a delicate operation, because it must not darken the colour of the oil or increase its free fatty acid content. The addition of a very weak solution of bicarbonate of soda has a stabilizing effect.

Degumming can also be done by using special additives that make gums insoluble: acetic acid, ammonium hydroxide, citric acid, oxalic acid, phosphoric acid, etc.

It is also possible, and simpler, to degum and neutralize in the same unit. The soap solution obtained by the neutralization of the free fatty acids carries off most of the gums when it settles. Consequently, before installing independent degumming equipment, the economic justification for doing so must be considered.

23/ Phosphatides, of which lecithin is the best known, are present in concentrations of 0.7-2.7 per cent in cotton-seed oil. Lecithin is extracted from soya on an industrial scale, but it is not interesting to extract it from cotton-seed oil, since its dark colour prevents its use for human consumption.

Neutralization

The purpose of neutralization is to remove the free fatty acids, which are present in crude oil in a concentration of 0.9-2.8 per cent.

Caustic alkali is the more commonly used base. It is very effective and bleaches better than the weaker alkalis. On the other hand, it saponifies some of the triglycerides. Other alkalis such as bicarbonate of soda have therefore been used occasionally, but have other drawbacks: they cannot reduce the free fatty acid content below 0.10 per cent (with caustic soda a figure of 0.01-0.03 per cent is possible) and their action has to be supplemented by other means.

The soluble substances contained in degummed oil include, besides the free fatty acids, very small amounts of monoglycerides and diglycerides, gossypol and other colouring agents, sterols and tocopherols (which it is certainly not necessary to remove), and various other imperfectly identified substances.

During caustic soda neutralization, the gossypol and other pigments react readily with the soda and are mainly removed in the soap stock, which is the residue of the operation.

Raw soap stock is a mixture of soap, non-glyceride organic impurities, water and emulsified oil.

Neutralization consists of two main steps: mixing, during which the soda reacts with the substances to be removed; and the breakdown of the emulsion and the precipitation of the neutralised substances.

Soda is effective only when diluted; the choice of dilution factor depends on numerous variables. Nearly all the water used for dilution passes, after neutralization, into the soap stock.

There are many neutralisation methods; their description, even in brief, would go beyond the scope of this study. The methods may be classified as follows:

- Caustic soda neutralization:
  - Batch process;
  - Continuous process;
- Weaker alkali neutralization:
  - Continuous process with alkaline carbonate followed by an alkali;
  - Continuous process with ammonia;
- Neutralization of miscella by caustic soda;
- Extraction of free fatty acids by other methods (solvents, steam, ion exchange resins, etc.).

Neutralization usually takes place at moderate temperatures and in several steps. The residues are separated by centrifuging. The oil is then freed of residual alkali, soap and water. The soap stock is purified, the neutral oil it contains is recovered, and it is then processed as necessary.

The total amount of free fatty acids and other substances lost from the oil in neutralization depends on the raw material and the process used. It is 3.5 to 9 times the free fatty acid content when that content is low, and 1.5 to 2 times the free fatty acid content when it is high. These losses are higher than those usually encountered for other seed oils of the same acidity.

To obtain a good quality oil, neutralization is often effected in two steps, the second of which uses a more concentrated alkali. If caustic soda is used, there is a further loss of oil.

Continuous neutralization gives results that are comparable in quality with those of batch processing. The secondary reactions that increase losses are better controlled, however, because of the shorter time during which the soap and oil, are in contact, which improves profitability considerably and allows the processing of oils with a higher free fatty acid content. Less skilled operatives are required, but the investment is justified only for processing capacities above 30 tons of seed every 24 hours.

Direct neutralization of miscella usually gives clearer oils and higher yields than traditional methods, but the investment cost is higher, the operatives have to be more highly skilled, and special precautions must be taken because of the risks of solvent explosions. Despite its advantages, the method is therefore little used.

The soap stocks obtained from concentrated soda solution and the gums (when they have not been removed beforehand by degumming) are very viscous. The centrifuges must therefore be powerful, in good condition, and easy to clean without dismantling.

Bleaching

The neutralized oil is usually golden yellow, which is suitable for food purposes, but it is sometimes reddish. When it is intended for the manufacture of solid fats, a white colour is preferred.

It is therefore necessary to bleach the oil so as to remove the various pigments not removed by neutralization. This is done with adsorbents in the form of bleaching earths or activated charcoal.

The bleaching of cotton-seed oil is quite similar to that of other oils. Traditional continuous or batch equipment is used. The maximum temperature is 100°-105° C. The bleaching earths must be used in concentrations of 0.5-2 per cent of the oil weight; higher concentrations (up to 10 per cent) are needed with charcoals.

Deodorization

Cotton-seed oil has a more objectionable odour and taste than other vegetable oils, because of the presence of foreign substances, mainly aldehydes and ketones. It must therefore be deodorized.

The deodorization of cotton-seed oil presents no special problems; the usual continuous, semi-continuous or batch equipment is used.

The treatment is fairly simple. As the substances to be removed are volatile, it is sufficient to heat the oil to a high temperature and inject steam to carry off the impurities, which are then condensed and evacuated.

In Europe, the parameters are typically a temperature of 180° C, an absolute pressure of 5-6 mm of mercury, and a cycle time of 4-5 hours. In the United States, where much higher temperatures are used (230°-240° C), the cycle time can be reduced to 1.5-2 hours. The colour thus obtained is lighter, and the cyclopropenic acids (malvalic and sterculic acids) are more or less destroyed, which is one of the aims of the treatment. Nevertheless, the equipment must be made of stainless steel and is therefore more expensive.

Deodorizers have capacities of 10-30 tons per 24 hours.

G. General remarks on investment strategy in cotton-seed processing

The processing proper of cotton-seed begins after ginning and consists, as has been seen, of the following operations:

Cleaning Delinting Dehulling and hull separation	Seed preparation
Flaking Flake cooking Oil extraction Oil refining	Separation of oil and cake
Degumming Neutralization Bleaching Deodorization	Oil refining

For each operation, an indication has been given of the capacities (in tons of seed per 24 hours equivalent) of the various types of equipment that can be used.

Seed-cotton ginning heads the list and can be done independently, since its main purpose is to provide fibre for textile use.

Oil mills can carry out all or part of the processing. They can also decide on the capacity required for each step, by choosing the capacity and number of each piece of equipment.

Many combinations are therefore possible.

One possibility is complete integration, from seed cleaning, or even ginning, to refining.

Another possibility is to set up a chain of plants, each of which does part of the processing.

Only a detailed study permits the determination in each case of the best economic choice, which depends on such factors as: the seed[24] tonnages to be processed and their geographical situation, the costs of transporting the material at various stages of processing, local labour and power resources, and the profitable use of by-products, (linters and hulls).

It may be more profitable to gin and prepare the seed (cleaning, delinting, dehulling, and separating the hulls) in small units (15 tons/24 hours) near the harvesting areas.

In some countries, delinting or dehulling may not be economically advisable.

Flaking and cooking are always associated with extraction. Hydraulic- or screw-press extraction may go with small plants (15-50 tons/24 hours), but the investment required for solvent extraction, with or without pre-pressing, are not usually justified except for large capacities (200 tons per 24 hours upwards).

The refining plant is not always installed in the oil mill, although international trade is only in neutralized oils. A choice is possible between local batch refining units, of less than 30 tons/24 hours capacity, and larger continuous units.

It is sometimes advisable to make provision for extraction and refining from other seeds. Such multipurpose units can be supplied more regularly and for longer periods of the year, at least when harvesting times differ; the equipment runs for more hours a year; the storage and manufacturing capacities are better matched to the tonnages processed; and since the total tonnage is greater, there are economies of scale for investment and the labour cost per ton.[25] Multipurpose units may have an extraction capacity of 700-2,000 tons/24 hours, and a refining capacity of 300 tons/24 hours.

24/ Seed in general, not only cotton-seed, since some equipment (extraction and refining equipment, for example) can be used to process several kinds of seed.

25/ In the countries where labour is expensive, the cost price decreases considerably when capacity increases considerably, since the work force is nearly the same for extraction units of 200 and 1,000 tons/24 hr capacity.

V. COTTON-SEED OIL

A. Quality standards

Crude oil

The price paid for crude oil depends on the quantity and quality (mainly colour) of the refined oil that can be obtained from it. The quantity and quality are measured by standard laboratory tests.

In order to facilitate commercial transactions and avoid disputes, grades have been defined, each of which corresponds to a quality of crude oil for which refining losses and the colour index must not exceed certain values.

In the United States, the standards are laid down by the National Cottonseed Products Association (NCPA) which distinguishes five main categories of crude cotton-seed oil.

- "Prime crude oil", when refining losses do not exceed 9 per cent, the AOCS colour index is below 7.6 Red, the free fatty acid content is under 3.25 per cent and flavour and odour after refining are pleasant;
- "Basis prime crude oil", when refining losses are below 20 per cent and the colour index does not exceed 12 Red;
- "Off crude oil", when refining losses are below 25 per cent and the colour index under 20 Red;
- "Reddish off crude oil", when refining losses are below 40 per cent and the colour index under 30 Red;
- "Low grade crude oil", when the oil does not meet the above specifications.

Refined oil

Usual trade classification

In the United States, NCPA recognises ten different grades of refined cotton-seed oil, according to extraneous material content, colour, taste and smell, and free fatty acid, water and volatile matter content.

(a) Neutralised oils:

- Choice summer yellow: must be free of visible extraneous material, clear and brilliant at melting point of stearine, colour index not exceeding 7.6 Red, sweet taste and smell, free fatty acid content not exceeding 0.125 per cent, and moisture and volatile matter content not exceeding 0.10 per cent;

- Prime summer yellow: specifications as above, except that the free fatty acid content must not exceed 0.25 per cent;
- Prime winter yellow: as prime summer yellow, but must pass the cold test laid down in the rules;
- Good off summer yellow: as prime summer yellow, but requirements for taste and smell are less stringent;
- Summer yellow: as prime summer yellow, except that the colour index must not exceed 12 Red;
- Off summer yellow: may be of inferior taste and smell, colour index must not exceed 12 Red, it must be free of visible extraneous material, free fatty acid content must not exceed 0.50 per cent, and water and volatile matter content 0.10 per cent;
- Reddish off summer yellow: as off summer yellow, but colour index not exceeding 20 Red and free fatty acid content not exceeding 0.75 per cent;

(b) Bleaching neutralized oil:

- Prime bleachable summer yellow: no visible extraneous material, clear at the melting point of stearine, sweet taste and smell, colour index after bleaching not exceeding 2.4 Red, free fatty acid content not exceeding 0.25 per cent, water and volatile matter content not exceeding 0.10 per cent;

(c) Bleached oils:

- Prime summer white: as prime bleachable summer yellow, except that the flavour must not be earthy;
- prime winter white: as prime summer white, but must also pass the cold test.

International specifications recommended by FAO (1969)

The characteristics of cotton-seed oil are:

Relative density at 20° C	0.918-0.926
Refractive index at 40° C	1.458-1.466
Saponification index 26/ (mg K OH/g oil)	189-198
Iodine index 27/ (Wijs)	99-119

26/ Indicates the average molecular weight of glycerides in the oil.

27/ Indicates the degree of non-saturation - the number of double bonds.

Unsaponifiable matter 28/	Maximum 15g/kg
Halphen reaction 29/	Positive

The FAO document gives as its quality requirements:

Acids: below 0.6 mg K OH/g oil

Peroxide: below 10 milliequivalents H_2O_2/kg of oil

Colour: characteristic of the product;

Smell and taste: characteristic of the product, without any strange smell or taste, or rancidity.

Impurities 30/ (maxima):

	Percentage	In mg/kg
Volatile matter at 105° C	0.2	
Insoluble impurities	0.05	
Soap	0.005	
Iron		1.5
Copper		0.1
Lead		0.1
Arsenic		0.1

The FAO standards specify the types and permissible concentrations of authorized additives, and also sampling and test procedures.

B. The composition of the free fatty acids in cotton-seed oil

The composition of the free fatty acids in cotton-seed oil is much the same whatever the variety concerned.

Table 15 compares the free fatty acid composition of cotton-seed oil with that of 11 other commonly used edible oils (fluid or solid).

28/ Unsaponifiable matter includes sterols, hydrocarbons, tocopherols, aliphatic alcohols, and terpenic alcohols.

29/ The Halphen reaction, which is peculiar to cotton-seed oil and certain rare oils (kapok oil, for instance), is based on the cyclopropenic fatty acids (malvalic and sterculic acid). Their concentration in cotton-seed oil varies from 0.04 to 2 per cent (average 1 per cent). There is usually more malvalic acid than sterculic acid. The acids have special biological properties and are mostly removed in refining.

30/ The gossypol is saponified during refining and is removed with the soap stock.

Table 15. Average percentages of free fatty acids in fluid or solid vegetable oils in the natural state a/

	Cotton-seed	Groundnut	Colza	Maize	Olive	Grape-seed	Soya	Sun-flower	Copra	Palm	Palm-kernel	Sesame
Saturated acids												
Caprylic C_8		-	-	-	-	-	-	-	5-10	-	3	-
Capric C_{10}		-	-	-	-	-	-	-	5-10	-	3-6	
Lauric C_{12}		-	-	traces	traces	-	-	-	45-50	-	50-55	
Myristic C_{14}	0.7-0.9	-	-	1	traces	-	-	-	18-20	1.4	12-6	
Palmitic C_{16}	16.7-24.9	6-8	1-6	10-16	7.5-20	6.4-6.7	6.5-12	3-6	5-7	38-43	6-8	7-9
Stearic C_{18}	0.9-2.4	3-5	-	1.5-2.7	0.5-3.5	2.6-2.8	2.3-4.5	2-3	3-5	1-6	1-4	4-5
Arachidic C_{20}	0.2-0.3	0.2	-	traces	traces	-	0.7-1	0.5-1	-	-	-	1
Behenic C_{22}		5-7	-	traces	traces	-	0-0.1	-	-	-	-	-
Mono-unsaturated acids												
Myristoleic C_{14}		-	-	-	-	-	-	-	-	-	-	
Palmitoleic C_{16} b/	0.3-0.4	-	-	traces	0.3-3.5	-	-	-	-	-	-	-
Oleic C_{18}	14.4-19.5	55-70	17-40	27-43	56-83	11.6-14.3	21-34	25-34	5	40-50	10-16	45-46
Erucic C_{22}			45-55	-	traces	-	-	-	-	-	-	
Di-unsaturated acid												
Linoleic C_{18}	51.8-59.0	14-28	14-30	42-60	3.5-20	73.8-79	49-59	57-66	-	8-11	0.5	35-41
Tri-unsaturated acid												
Linolenic C_{18}			1-4	0.1-1.9	-	-	2-8.5	-	1	-	0.1	

a/ Without hydrogenation of the fluid oils.

b/ Also called hexadecenoic.

Table 16. Composition of cotton-seed oil compared with that of 11 other edible oils

Cotton-seed oil free fatty acid content (%)	According to P. H. Mensier, 1957	According to J. L. Iverson 1969	According to Achaya, Chakrabarthy and Meara (India), cited by Murti and Achaya	According to Mitchell, 1943 (United States)	Sources appearing in Pilette and Bagot
Saturated acids					
C_{14} : 0 (myristic)	1.4	0.7 - 0.9	0.2 - 1.0		
C_{16} : 0 (palmitic)	23.4	16.7 - 24.9	23.1 - 28.1		
C_{18} : 0 (stearic)	1.1	0.9 - 2.4	1.8 - 3.2		
C_{20} : 0 (arachidic)	1.3	0.2 - 0.3			
Total	27.2	approx. 23.5	approx. 28.7	27.0	25.4 - 29.5
Mono-unsaturated acids					
C_{16} : 1 (palmitic)	2.0	0.3 - 0.4	0.6 - 2.5		
C_{18} : 1 (oleic)	22.9	14.4 - 19.5	15.6 - 23.7	19.0	22.2 - 27.3
Total	24.9	14.7 - 19.9	approx. 21.2	19.0	22.2 - 27.3
Di-unsaturated acid					
C_{18} : 2 (linoleic)	47.8	51.8 - 59.0	47.3 - 56.5	54.0	42.0 - 46.2

C-34

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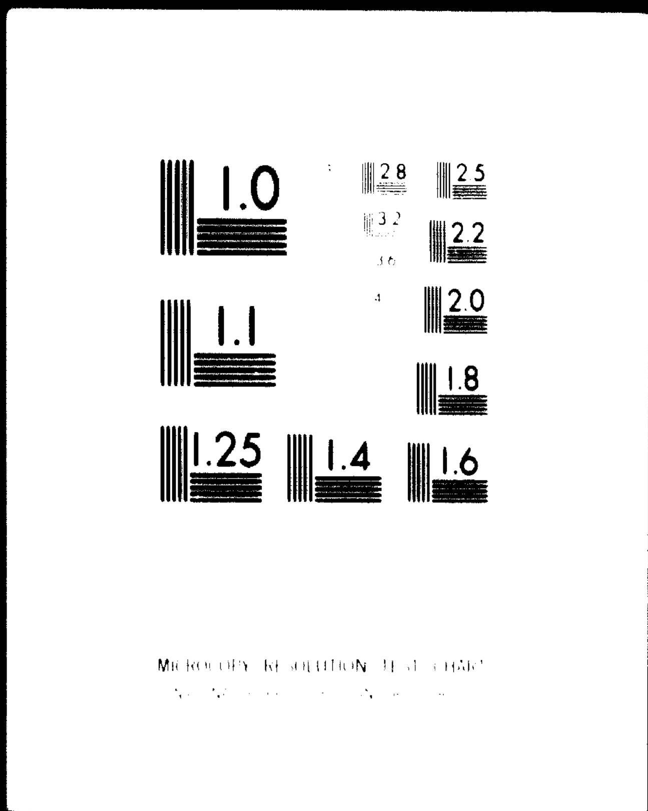

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The figures for cotton-seed oil are those measured by John L. Iverson (Food and Drug Administration, Washington, United States) in 1969, by gas chromatography.31/ Table 16, which sets out the results of earlier measurements, shows some disparity due to differences between cotton-seed oils and different test procedures.

Table 17 shows the iodine indices and solidification temperatures of the main vegetable fats, arranging in order of decreasing unsaturation:

Table 17. Physical characteristics of some edible oils

Natural oil	Iodine index	Solidifation temperature (° C)
Sunflower	115-135	-18.5 to -16
Soya	121-142	-18 to -8
Maize	111-128	-15 to 0
Cotton-seed	99-119	+2 to +4
Colza	94-105	0
Sesame	100-108	-6 to -3
Groundnut	84-105	-2 to +3
Olive	78-95	-9 to 0
Palm	44-56	+24 to +30
Palm-kernel	16-23	+19 to +30
Copra	7-9.6	+14 to +25

Source: FAO Commodity Policy Studies, No. 22, Rome, 1971

Cotton-seed oil belongs to the first group, the extreme positions in which are filled by sunflower and colza oils.32/ The oils of this group have a high linoleic acid content, with the exception of Colza oil (C_{18} : 2 - a free fatty acid with 18 carbon atoms and two double bonds). As a result:

31/ For the other oils, the material used consisted mainly of documents from ITERG (Institut technique d'études et de recherches des corps gras).

32/ Grape-seed oil also belongs to the first group.

- During storage, they rancify more than other oils;
- They are less resistant to changes on heating, and are therefore unsuitable for frying;
- On the other hand, the high linoleic acid content is appreciated by nutritionists, since many writers feel that there should be more linoleic acid in food for human consumption, so as to counter high cholesterol levels and their consequences;
- Linoleic acid is also an essential fatty acid that children, in particular, are recommended to take.

Linolenic acid must also be considered. It is undesirable, because it oxidizes easily, producing substances that should be kept out of food. Unlike soya and colza oils, cotton-seed oil does not contain linolenic acid, and this is an advantage, although hydrogenation, which is mainly intended to solidify fluid oils, permits the almost complete elimination of linolenic acid. This can be seen by comparing the composition of natural and hydrogenated soya oils.

Main fatty acids	Soya oil in the natural state	Hydrogenated soya oil
$C_{16}:0$	10.2	9.7
$C_{18}:0$	4.6	4.1
$C_{18}:1$	25.6	51.1
$C_{18}:2$	51.8	35.1
$C_{18}:3$	7.8	0.0
	100.0	100.0

Hydrogenation is therefore less necessary for cotton-seed oil than for soya oil, since for the former the benefit is technical (modification of consistency) rather than nutritional.

Colza oil is unique in that it contains little linoleic acid but a large amount of erucic acid which has been blamed for provoking cardiopathy in humans and animals. This has led to decreased consumption in some countries. Geneticists have selected varieties of colza seeds in which erucic acid is replaced by oleic acid.

The first group of oils also includes grape-seed oil which is manufactured in very small quantities. Grape-seed oil has the highest linoleic acid content.

The solidification temperature of cotton-seed oil is the highest of all fluid oils. It becomes cloudy at 5^{o}-7^{o} C, which is a drawback in winter and for storage in refrigerators; it is cleared by winterization (see chapter IV.E.).

The second group of oils (sesame, groundnut, olive), to which colza oil could also be added, consist mainly of a mono-unsaturated fatty acid: oleic acid. They are more stable than the oils of the first group and are suitable for frying.

The other vegetable fats mentioned in table 17 are solid oils, - solid at normal temperatures, that is. Palm oil contains a good deal of oleic acid, while palm-kernel oil, and especially copra oil, contain mainly saturated short-chain fatty acids. They are used for making margarines and shortenings, and are suitable for cooking and frying.

C. Interchangeability with other oils

The criteria governing the choice of fats depend on the intended use.

The characteristics to take into account include:

- The percentage of saturated, mono-unsaturated, and poly-unsaturated fatty acids;
- The exact nature of the fatty acids;
- The solidification temperature;
- The viscosity at different temperatures;
- The taste, smell and colour.

Cotton-seed oil, which belongs to the group of oils rich in poly-unsaturated fatty acids, is less stable than the oils of the second group or the solid oils. It is more stable than soya oil, however, because of the absence of linolenic acid, which is highly unstable, and the presence of tocopherols, which are natural oxidation inhibitors. Gossypol would have the same effect, but it is removed almost completely in refining.

Hydrogenation has generally permitted a greater interchangeability of fats. Oils with high poly-unsaturated free fatty acid content store better without rancification and become more heat-resistant; they also acquire a solid or semi-liquid consistency suitable for margarine manufacture.

Salad oils

"Salad oils" is the term used for any oils used directly, or in emulsion, to season cold foods. They must be fluid, which excludes all solid oils, except in hot countries. Fractionation of palm oil produces a liquid salad oil.

Theoretically, there is a high degree of interchangeability of oils, but local culinary habits limit it. Flavour is a decisive factor; although oils can be deodorized, they cannot be given a flavour artificially.

In practice, there are three patterns to consider:

In countries where purchasing power is low, the public continues, as a result of tradition and necessity, to show a preference for oil made from local raw materials. If there is none, the cheapest oils are usually imported.

In developed countries, the trend is to blend several fluid, neutral-flavoured oils, except where certain sectors of the population prefer more distinctive oils (olive oil, for example).

For use in cold dressings (mayonnaise, etc.), the flavour of the oil is of little importance, since it is masked by the flavour of the other ingredients. The most important requirement is that oil should emulsify easily.

Cotton-seed oil is eminently suitable for the following three purposes:

- Traditional consumption (sometimes there is none, but it can be created or increased) in cotton-producing countries with low purchasing power;
- For inclusion in salad oil blends in the developed countries. Cotton-seed oil is useful in that it balances the fatty acid content by its high linoleic acid content: this is also a dietetic argument (but one that is seldom encountered outside the United States). It thus competes with sunflower, maize and grape-seed oils, and also unhydrogenated soya oil, whose high linolenic acid content is a drawback.
- Use for cold dressings. This is a much narrower market. Cotton-seed oil produces the right kind of emulsion.

Frying and cooking oils

Interchangeability is reduced, because an oil is needed that is not changed by heat (frying raises the temperature to 180°–220° C).

Pure cotton-seed oil, like the other oils in the first group, is suitable only for low temperature cooking. It deteriorates less than soya or colza oil, however, because of its lower linolenic acid content.

After hydrogenation, the oils of the first group become interchangeable with those of the second group and with solid oils for cooking and for frying.

A blend of oils, whose linolenic acid content is deliberately limited ($<$ 2 per cent), is being increasingly sold for this purpose.

Pure ground-nut, copra or palm oil is excellent for cooking and frying; olive oil is also appreciated in the Mediterranean countries, despite or because of the strong flavour it imparts to the food.

Spreading fats (margarine)

Margarine must have a pleasant taste, and be of a consistency (plasticity, spreadability, melting point) similar to that of butter.

With hydrogenation, fats are almost completely interchangeable.

The current trend is to increase the proportion of linoleic acid to meet the criticism of nutritionists. There is even a small but growing market for high linoleic acid diet margarine.

This could help to develop the use of unhydrogenated cotton-seed oil, but it seems that sunflower and maize oils are used increasingly for this purpose.

Fats used in the manufacture of pastry, biscuits, cakes, and other flour-based products

Since in these industries the fat, which is finely dispersed in an aerated and liquid medium, is heated during baking, its resistance to oxidation and hydrolysis is a very important factor. Its rheological properties (plasticity, creaminess, etc.) are also extremely important.

With hydrogenation and other industrial processing techniques (inter-esterification, fractionation techniques), fats are almost totally interchangeable. In practice, solid oils and animal fats are widely used.

Pure (unhydrogenated) cotton-seed oil and other fluid oils cannot be used.

Animal feeds

For "milk substitutes" (meaning foods for young mammals), the fats employed are mainly suet, copra and palm oil, and lard.

Fats are added to dry feeds (mixed feed manufactured industrially or by the farmer himself) to improve the food intake of adult animals. The animal stomach is not as demanding as the human stomach; so inferior fats can be used. Price is then the main factor; interchangeability is restricted to animal fats and certain solid oils.

Uses of fats other than for food

For many industrial uses, interchangeability is limited, and does not extend to cotton-seed oil:

- For paints and coatings, siccative oils are used that have a high poly-unsaturated fatty acid (linolenic type) content (linseed oil, aleurone oil, some soya oil);
- For the manufacture of plastic or artificial textiles, castor oil is used;
- For hot galvanizing or cold laminating, palm oil is used.

There is interchangeability, however, in soap-making, in which fats may be combined with a base to give soap (with glycerol recovery) or fatty acids may be directly combined with a base. Nevertheless, interchangeability is limited by the quantities of saturated and unsaturated fatty acids that must be used. For the manufacture of fatty acids, fats are chosen solely according to the amounts of acid or acids that can be obtained by fractionation. The choice is reduced still further if certain acids are wanted that are found only in particular fats and cannot be produced by hydrogenation from unsaturated acids with the same number of carbon atoms. The choice is much greater when an acid of the stearic type $C_{18} : 0$ is wanted: it can be obtained by hydrogenation of oleic acid $C_{18} : 1$ or linolenic acid $C_{18} : 3$, which means from nearly all fats and oils.

In conclusion, oil interchangeability varies according to use, but has been greatly extended by hydrogenation.

Cotton-seed oil is most directly interchangeable with the other oils of the first group (sunflower, soya, maize, colza).

VI. COTTON-SEED CAKE

A. Cake characteristics

In the United States, the term "cotton-seed cake" is used for cake obtained from hulled or unhulled cotton-seed after extraction of the oil by mechanical means - hydraulic or screw presses - and the term "cotton-seed meal" is used for cake from which the oil has been extracted by solvents.

The composition of cotton-seed cake varies, depending on:

- The species of cotton used;
- The care taken in delinting and dehulling, which are sometimes dispensed with (see chapter IV, A. and B.);
- The conditions of cooking, which affect the free or protein-bound gossypol content;
- The oil extraction process and the way it is applied (for example, the speed of rotation of the press shaft, or the solvent chosen);
- The proportion of certain by-products added to the cake (some hull particles, some of the impurities separated in crude oil refining).

Cake is therefore encountered with the following protein (N x 6.25), oil, water, crude fibre and ash contents, these being the only constituent usually measured (see table 18):

Table 18. Composition of various types of cotton-seed cake and meal (percentage)

	Proteins	Oil	Water	Crude fibre	Ash
Hulled cake	20 - 30	5 - 8	4 - 15	23 - 28	9 - 10
Dehulled cake	37 - 43	3 - 7	7 - 9	10 - 15	7 - 9
Meal	40 - 45	0.5 - 2	9 - 11	10 - 18	2 - 2.5

There are cakes for which the figures fall outside the ranges indicated in the table, but they are a minority (mainly screw-press extracted cake, whose oil content may be as high as 15 per cent).

Cotton-seed cake also contains varying amounts of other undesirable substances: free or bound gossypol, aflatoxins, pesticides, solvents, and insect scraps (see chapters I.G. and III.A.).

The regulations of the United States NCPA require a minimum protein content of 36 per cent.[33/] First grade cake must have a good smell and colour, and be free from mould. The cake can be delivered as it is, or ground to varying degrees of coarseness, from nut sized lumps to flour. A special category - "low gossypol" - has a maximum free gossypol content of 0.04 per cent.

B. Amino-acid composition, and use for animal feed

As has already been stated in chapter III, the available lysine content, as a percentage of proteins, is:

- 2.50-3 per cent for cotton-seed cake;
- 3.10-3.60 per cent for cotton-seed meal after oil solvent; extraction with pre-pressing;
- 3.40 per cent for meal obtained by direct hexane extraction of oil;
- 3.70-4.40 per cent for acetone-hexane-water azeotrope extracted meals.

As lysine is the first limiting factor on cotton-seed protein, (the other deficient amino-acids are isoleucine, methionine and threonine), the oil extraction process greatly influences the nutritive value of cake.

Table 19 allows a comparison of the amino-acid composition of cotton-seed cake and six other cakes.

As far as the lysine content is concerned, it can be seen that soya and colza proteins have a higher nutritive value than cotton-seed protein, as has already been noted, and ground-nut, sunflower, sesame and linseed proteins are comparable or inferior to cotton-seed protein, depending on whether the cotton-seed cake had the oil extracted from it by solvent or press.

There are, however, other factors to be considered:

Colza cake contains sulphurous constituents whose hydrolysed products have toxic and antinutritional effects. Although physico-chemical or fermentation detoxification processes exist, colza cake is of limited use. The recent breeding of new species free of such undesirable components should

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33/ Except for unhulled oakes, for which the minimum content is reduced to 22 per cent.

Table 19. Amino-acid composition of various cakes
(percentage)

Essential and semi-essential amino-acids	Cotton-seed cake	Soya cake	Colza cake	Groundnut cake	Sunflower cake	Sesame cake	Linseed cake
Arginine	11.2	7.0	5.7	11.0	8.7	10.0	8.9
Cysteine	2.0	1.2	1.2	1.4	2.1		1.7
Histidine	2.7	2.8	2.6	2.4	2.4	2.4	2.2
Isoleucine	3.9	4.7	3.9	3.6	4.6	3.6	4.5
Leucine	6.1	7.9	7.0	6.5	6.1	6.1	5.9
Lysine	2.5-4.4	6.3	5.9	3.5	3.5	2.7	3.7
Methionine	1.5	1.3	1.8	1.1	1.8	2.1	1.7
Phenylalanine	5.2	5.3	3.9	5.5	4.7	4.5	4.5
Threonine	3.4	3.9	4.4	3.0	3.6	3.5	3.8
Tryptophen	1.4	1.3	1.3	0.9	1.5	1.2	1.6
Tyrosine	3.2	3.8	2.3	4.5	2.3	4.7	2.2
Valine	4.9	5.0	5.0	4.3	5.6	4.8	5.8
Average protein content of cake	40-45	44-50	35	45-50	37-40	45	34-38

solve the problem, but it will be some time before they are cultivated generally, like glandless cotton-seed. Morsover, the technique of dehulling colza seed has not yet been perfected.

Ground-nut cake does not contain noxious substances, but is often contaminated, as a result of gathering and storage conditions, by moulds that release aflatoxins.

Sunflower cake does not contain noxious substances.

The nutritive value of a caks may be adjusted within limits by the addition of industrial amino-acids, especially lysine. Such a step must, however, be economically justified.

Generally speaking, soya cake is by far the most widely used, and the laws of the market force the prices of other oakes to align themselves relative to soya prices.

The manufacturers of animal feeds are trying to increase profitability constantly, and introducing not only the cakes mentioned in table 24, but also additional lysine (and possibly methionine), non-protein nitrogen (urea), lucerne flour, plant silage, beet pulp, fish meal, bone meal, blood meal, milk powder, lactoserum powder, etc., according to the needs of ruminant or non-ruminant, young or adult stock.

For a long time, cotton-seed oake was not used as a feedstuff but was simply ploughed back as a fertilizer. This is still done,34/ but the use of cotton-seed cake as an animal feed is spreading, especially in the producing countries.

Added to cereals, green forage, etc., it is often used to prepare mixed feeds for ruminants, which seem to be unaffected by the free gossypol and can even digest some of the cellulose of the hulls.

Non-ruminants (poultry and pigs), however, are more affected by the free gossypol, and the cellulose does not provide them with any nourishment. As has been indicated (see ohapter I.C.), the combined action of gossypol and oyclopropenic acid causes an unpleasant change in the colour of egg yolks.

34/ Another practice used to be to feed cattle with the seeds just as they were after ginning, without extracting the oil.

Every effort must therefore be made to reduce as far as possible the free gossypol content - without lowering protein quality - and leave few hull fragments. Glandless cotton-seed varieties will widen the market. The control of aflatoxin contamination is also an important factor for non-ruminants.

Cotton-seed cake can be stored and transported in bulk or packed. It should not be re-moistened beyond its normal moisture content, or recontaminated by moulds, micro-organisms, insects and so on.

C. Pelletization

Pelletization is a process whereby finely divided cake, often powdery and sometimes of low density, and nearly always difficult to handle, is compacted and extruded in larger particles, under the action of heat, moisture and pressure.

Modern equipment comprises:

- A screw conveyor that lifts the cake to the top of the plant;
- A paddle mixing machine, with a shaft turning at 150-500 rpm. High-pressure steam is introduced to heat and moisten the cake, Water is added if the cake is too dry.
- A pelletizing chamber, with two or three rollers inside. A perforated drum and the rollers rotate in the same direction, at a speed of 160-400 rpm. The meal is pressed between the drum and the rollers, emerges through dies, and is cut by two or three fixed blades.

When the pellets have been shaped, they must be cooled and dried, since their water content may rise to 15-16 per cent during the process and the temperature rises to 80°-90° C. This is done by blowing air through a uniform layer of pellets. The moisture content then falls to 10-12.5 per cent, and their temperature to slightly above ambient. The drying and cooling machines may be of the horizontal or vertical type.

The equipment may be preceded by a cake-cleaning device, and followed by a screen.

Occasionally, corrugated rollers are used, to grind the pellets into smaller particles.

At present, most pellets are made from solvent extracted meals, supplemented with refining impurities, which act as lubricants that facilitate pelletization and increase pellet cohesion.

Equipment capacity is 1 ton per hour for every 10 HP; power varies from 30 to 300 HP.

The volume of the pellets varies from 4.1 to 14.3 cm^3.

VII. BY-PRODUCTS AND RESIDUES

In order to establish from the outset the importance of the two main by-products, linters and hulls, in relation to oil and cake (themselves by-products of cotton staple), table 20 shows the breakdown by weight and value of the material obtained from one ton of cotton-seed in the United States in 1970.

Table 20. Relative importance of various cotton-seed products and by-products

By-product	Weight in pounds	Average price in cents/lb	Value in dollars	Percentage of total value
Oil	325	14.70	47.78	50.5
Cake (41% protein)	927	3.68	34.11	36.0
Linters	194	3.83	7.43	7.8
Hulls	468	1.15	5.38	5.7
TOTAL AMOUNT	1 914	4.95	94.70	100.0

Source: US Fats and Oils Statistics.

The figures show that in the United States linters and hulls account for about 8 and 6 per cent respectively of the value of cotton-seed after ginning.

A. Linters

Quality grades

As was seen earlier (chapter IV.A.), saw-delinting was the most frequently used process and could be carried out in one run, which produced "mill-run" linters, in two successive runs, which produced "first-cut" and "second-cut" linters, or even in three or four runs.

The weight of linters removed depends on the initial weight around the seed (0-12 per cent depending on the species), the delinting process chosen, the way the process is applied, and the subsequent cleaning.

In the United States, linter grading is based on four parameters:

- The distribution of the linter fibre length. First-cut staple is generally 2-6 mm long, and second-cut 1-3 mm. If there is only one delinting operation, the linters consist of fibres of widely varying lengths, which is a drawback for certain uses (the wider the spread of fibre lengths, the lower is the market value in general);
- The extraneous material content (mainly vegetable scraps, dust, and hull pepper);
- The colour (olive green, creamy white, pinkish, etc.);
- The character, which combines three features: the range of fibre lengths, softness or coarseness, and the degree of crimping and knotting. The character depends upon the soil, climate, and species. It is described by one of the three following names: western, valley, south-eastern.

Using these parameters and users' requirements, the United States distinguishes the following seven grades of linters, given here in order of decreasing fibre length:

- Classes 1 and 2 are usually first-cut;
- Class 3 is first-cut or mill-run;
- Class 4 is mill-run;
- Class 5 is mill-run and second-cut;
- Classes 6 and 7 are second-cut.

Classes 1 to 4 are used for textiles, and classes 5 to 7 for chemical applications as will be seen.

For chemical applications, the chemical purity of the linters is most important, because the cellulose required must be as pure as possible. The material must be very clean, with a minimum oxy-cellulose,[35/] wax and oil,[36/] ash,[37/] and especially iron[38/] content. Second-cuts are therefore better than first-cuts, since they contain less impurities. Staple length is nevertheless not entirely irrelevant, since very short fibres could be lost during washing.

35/ Oxy-celluloses are soluble in alkalis. Linters contain 10-30 per cent oxy-cellulose.

36/ Waxes and oils are soluble in ether and benzene. Their concentration must not exceed 2 per cent.

37/ The usual concentration is 2.5 to 3.5 per cent. It should be kept below 3 per cent.

38/ The iron content must not exceed 500 ppm.

Uses of linters

Textile applications

The United States makes the most use of linters for textiles.

Linters may be used as they are for making cotton wool or stuffing mattresses, furniture (armchairs, sofas, headboards), harnesses, etc. Classes 2, 3 and 4 are used for such purposes.

The textile industries make particular use of classes 1 and 3 for making felt or yarn for the manufacture of string, wicks, household cloths, blankets, dressings, etc.

Classes 1 and 2, and sometimes 3, may also be used in paper-making. Treatment of the linters with ethylene oxide (hydroxyethylation) improves the characteristics of the linters.

Chemical applications

Short fibres are preferred for chemical applications, which have been developed in certain countries such as India.

Linters are preferred to competing raw materials such as wood pulp because of their higher α cellulose content and because they are free of pentosanes and lignin.

Without going into detail regarding chemical reactions or competing materials for each use, one may mention the following main markets for linters for chemical applications:

- Cellulose acetate production for the manufacture of rayon (viscose) and photographic film bases and for injection moulding;
- The production of nitrocellulose, a well-known explosive. Linter prices tend to rise in war-time, as happened in 1950 in the United States (Korean war). Nitrocellulose has many other uses, however: automobile paints, artificial leather, paper coatings, photographic films, etc.;
- Carboxymethyl cellulose and other similar derivatives, used as thickeners in the paper-making, textile, food, detergent and other industries.

For all chemical applications, linters must face competition from cheaper products (wood pulp, synthetics, etc.).

Economic considerations

As was pointed out in chapter IV.A., saw-delinting may be pointless if there is no adequate market for the linters. Saw-delinting requires heavy investment, consumes power, and produces dust and noise.

Other delinting processes (burning, acid- or abrasion-delinting) are possible. They destroy the linters or lower their quality, but are cheaper.

When all the seed supplied to the mill is very dirty, the linter grade will be poor.

However, the effect of delinting on other processing steps must be taken into account. The dehulling of seeds with more than 4 per cent linters is technically difficult, and involves oil and kernel losses; and the kernels obtained after dehulling undelinted seeds contain less hull scraps.

Calculations made by S. Clark (see chapter IV.B.) show that if the average selling price of linters goes above 4 cents a pound, it is best to delint before dehulling; below 3 cents a pound, delinting may be dispensed with or acid-delinting can be made.

In practice, it seems that saw-delinting is always used in the United States, in order to keep the linter content under 4 per cent.

Delinting can be done in one mill-run, two runs, (first cut and second cut), or three or four runs, depending on the cost of each option and the selling price of the linters produced.

Generally speaking, second cuts sell better than the others, and this encourages two-run delinting. Price fluctuations caused by factors outside the industry are so large, however, that profitability calculations may lead to totally different conclusions from one year to another. The prices determine whether seed should be delinted in one or two runs, and the equipment must be adjusted to keep a suitable amount of linters on the seeds.

B. The hulls

The composition of the hulls was given in chapter I.F.

After grinding, the hulls can be separated by screens or cyclones into two fractions:

- Hull fibres, which contain about 70 per cent α-cellulose, with an average length of 3 mm;
- Hull pepper (also called "hull bran"), which contains little α-cellulose but large amounts of pentosane and lignin.

The constituents could be even better separated by physico-chemical processes:

- As lignins and pentaosanes dissolve in hot (130°-140° C) alkaline solutions, almost pure α-celluloses could be separated and used for manufacturing rayon;
- By processing the hull pepper with water, which removes gums and ash, and then with sulphuric acid, the pentosane molucules are broken down and xylose is obtained. Pentosanes can also be converted into furfurol, which is used for manufacturing plastics and paint.
- Acid hydrolysis of cellulose gives glucose and, as a solid residue, lignin, the applications for which are limited.

Hulls are in fact one of those many agricultural by-products (sugar-cane bagasse, maize ears, oat and rice seed coats, coconut hulls, etc., that it is difficult to put to profitable use.

Use as fertilizer

Because of their low density and their composition, hulls are excellent humus fixers.

Use as fuel

The calorific value of husks is about 40 per cent of that of fuel oil. However, they must be burnt only in furnaces made from fire-proof bricks with a high alumina content, since otherwise the ash could provoke corrosion of the bricks.

Use as animal feed

This is by far the most frequent use. Despite their low nutritional value (approximately 50 per cent of that of a good-quality hay), a lack of vitamin A and some essential mineral salts, they can be easily digested by ruminants when mixed with feeds.

In some countries, therefore, all the hulls are left with the cake (there is no dehulling), although the oil yield is reduced (cf. chapter IV.B.).

The nutritive value of hulls could be increased by degrading the fibre with acids and alkalis, so as to increase its digestibility.

<u>Other uses</u>

Some potential uses are: manufacture of active charcoal - paper-making - separate extraction of cellulose, lignin, xylose and furfurol.

C. Soap stock

Soap stock is the by-product obtained by neutralization of cotton-seed oil.

It is always dark in colour, and its composition varies greatly, since it depends on the quality of the crude oil before refining, the neutralization process used and whether the oil is degummed before hand.

Soap stock contains water, soda soap, neutral oil, fatty acids, pigments (gossypol especially, in concentrations from 0.01 to 11 per cent), phosphates, resins, carbohydrates and so on.

The simplest use of soap stock is as raw material in the manufacture of soaps and detergents. This is a frequently used way of disposing of soap stock, but is not recommended because of the many impurities in the soap stock which adversely affect the quality of the finished product.

The fatty acid content of soap stock (either free or bound as soda soap) makes it worth while to recover these acids. Soap stock is treated with sulphuric acid, which combines with the soda and frees the fatty acids, in a continuous or discontinuous operation. The fatty acids may then be distilled, if necessary, so as to remove all residual impurities, and to separate relatively pure palmitic acid from a mixture of oleic and linoleic acids. The distillation residue, or "cotton pitch", is a mixture of polymerized fats, more or less modified fatty acids, various unsaponifiable substances, and impurities. Cotton pitch is a black amorphous substance which is waterproof and can therefore be used in the manufacture of varnishes, paints, coatings (wire insulation, for example), bitumens, and the like.

The fatty acids derived from soap stock are mainly used in soap manufacturing. They are also used as raw materials in the chemical industry (compounds for natural and synthetic rubber, paints, varnishes and coatings, plastics, lubricants, metal treatments, cosmetics and toilet articles, cosmetology, insecticides, and the like).

D. The bleaching earths used

The oil content of the bleaching earths used varies according to the type of earth employed, whether active charcoal was used, and what process was used for drying the filter-presses (air or steam injection). It may be anywhere between 20 and 60 per cent. The oil deteriorates and oxidizes rapidly in air, and can be recovered in two ways: autoclaving with an alkaline solution, or solvent recovery in a suitably adapted filter-press.

Since the oil recovered by the second method is not exposed to the air, it can be recycled, after solvent removal, into the edible oil manufacturing process. The equipment required is very expensive, however, and must be located well away from other installations because of the risk of explosion (especially when hexane is used).

Oils recovered by the first method can be used for making soap, distilled fatty acids and cattle feed.

E. Other by-products

Phosphatides (see chapter IV.F.), which contain lecithin, may also be recovered, but the dark colour of the lecithin makes it uncompetitive with soya lecithin.

The deodorization distillates are 0.1-0.3 per cent of the oil yield, They consist of free fatty acids, oxidized fatty acids, aldehydes and a large proportion of unsaponifiable substances that include sterols. Their recovery has been less studied than that of soya oil deodorization distillates.

F. Environmental effects

Cotton-seed oil mills do not cause much pollution.

Nevertheless, whenever local conditions require that only high-quality water is discharged, chemical, and possibly biological, purification will be necessary, since:

- The extraction waters contain traces of solvent when solvents are used;
- The water from refinery degumming and washing contains, as has been seen, various substances;
- Deodorization water contains soluble or emulsified distillates.

For all effluents, decanters must be fitted so as to allow the recovery of fats.

As to atmospheric pollution, the air around an oil mill is usually fairly free of pollution, except the air from the heater chimneys, which contains sulphur if the fuel used is a petroleum product, or ash if the hulls are burnt.

An oil mill is noisy (conveyors, delinters, dehullers, presses) but the noise level can be lowered by taking certain precautionary measures during installation.

One type of pollution is specific to cake stores: when the cakes are spread on the ground and moistened, they form a sticky paste that may ferment. The stores must be kept clean.

VIII. THE COTTON-SEED MARKET

A. The main producing countries

Areas under cultivation and fibre yield and production from 1973/74 to 1976/77 (provisional figures) for each country are given in chapter I, where information will also be found on the species grown in the main producing countries. This is important for the seed processing industry because the amount of linters varies greatly from species to species, and protein content also varies.

According to FAO statistics, the movement in world cotton-seed production between 1970 and 1976, in millions of tons, were as follows:

1970	1971	1972	1973	1974	1975	1976
22.1	23.5	24.7	24.9	25.9	22.9	23.6

There was almost no movement; the ratio between the highest production (1974) and the lowest (1970) is only 1.17.

Table 21 shows how the production is distributed among the main producing countries, for the years 1973, 1974, 1975, and 1976. Four countries produce almost two-thirds of world production: China, India, the Soviet Union, and the United States (there is some uncertainty about the statistics for China).

Table 21. Cotton-seed production by country
(thousand tons)

Country	1973		1974		1975		1976	
	Quantity	Percentage of total	Quantity	Percentage of total	Quantity	Percentage of total	Quantity	Percentage of total
USSR	4,970	20.0	5,460	21.1	5,130	22.3	5,400	22.9
China	4,295	17.2	4,295	16,6	4,337	18.9	4,900	20.7
United States	4,550	18.3	4,134	16,0	3,175	13.8	3,661	15.5
India	2,398	9.6	2,580	10,0	2,450	10.7	2,292	9.7
Pakistan	1,318	5.3	1,268	4.9	1,020	4.4	1,029	4.4
Brazil	1,215	4.9	1,070	4.1	1,015	4.4	795	3,4
Turkey	821	3.3	958	3.7	745	3.2	750	3.2
Egypt	862	3.5	753	2.9	730	3.2	680	2,9
Sudan	358	1.4	432	1.7	432	1.9	208	0,8
Mexico	572	2.3	852	3.3	335	1.5	369	1.5
Iran	406	1,6	411	1.6	328	1.4	275	1.2
Argentina	244	1,0	237	0.9	270	1.2	258	1.1
Syrian Arab Republic	248	1.0	244	0.9	240	1.0	230	1.0
Colombia	243	1,0	283	1.1	210	0.9	215	0.9
Nicaragua	178	0,7	225	0.8	200	0.9	199	0.8
Peru	148	0.6	125	0.5	141	0.6	135	0.6
Other countries	2,074	8.3	2,573	9.9	2,206	9.6	2,224	9.4
Total	24 900	100,0	25 900	100,0	22 964	100,0	23 620	100,0

Source: FAO Production Yearbook, 1976, Rome, 1977.

B. Comparison with other oleaginous plants

Table 22 shows (in millions of tons) the production of the main oleaginous seeds from 1970 to 1976.

Table 22. Production of main oilseeds 1970-1976
(million tons)

Seed	1970	1971	1972	1973	1974	1975	1976
Soya	46.5	48.5	52.3	62.3	56.9	68.9	62.1
Cotton	22.1	23.5	24.7	24.9	25.9	22.9	23.6
Groundnut	18.4	19.2	15.9	17.0	17.3	19.6	18.5
Sunflower	9.9	9.7	9.5	12.0	10.9	9.4	10.0
Colza	6.7	8.1	6.8	7.1	7.2	8.4	7.5
Copra	3.6	3.9	4.4	3.7	3.6	4.5	4.9
Linseed	4.1	2.8	2.5	2.4	2.3	2.5	2.5
Sesame	2.2	2.0	1.9	1.9	1.9	1.9	2.0

Source: FAO Production Yearbook, 1976, Rome, 1977.

The seeds are classified in order of decreasing tonnage.

Cotton is second, but is far behind soya.

It is also useful, however, to compare the average oil and protein contents of the various seeds, with the exception of linseed, the oil from which cannot be used for human consumption.

Table 23. Protein and oil contents of various oilseeds

Seed	Average percentage content of oilseeds	
	Oil	Protein
Soya	20	42
Cotton	19	21
Dehulled groundnut	48	19
Colza	51	20
Sesame	50	25
Sunflower	39.6	13.6 a/
Copra	69	7.4

Source: UNIDO, ID/126.

a/ Some authors give higher figures, from 16 to 24 per cent.

According to Table 24, the position of cotton-seed is not particularly good: although its oil content is practically the same as that of soya, the latter contains far more proteins; and groundnuts, colza, sesame and sunflower seeds contain far more oil,[39] which is the main factor in turning seed to profitable use.

This reasoning is only partially valid, however, since it neglects differences in yield per hectare and makes no allowance for lint, which is peculiar to cotton and the basis of its value; cotton-seed is a by-product of the fibres.

As a result, the trade prices of cotton-seed oil and cake are not based on specific production costs, but are aligned with those of the other oils and cakes - particularly soya - by coefficients that raise or lower the price depending on differences in the composition of the oil (cf. chapter V) and cake (cf. chapter VI). The coefficients also fluctuate according to the market (supply and demand ratio), stock levels, crop forecasts and so on.

C. International trade in cotton-seed

Only a minute proportion of world production - about 1 per cent - is traded internationally.

Cotton-seed contains little oil, has a large proportion (40 per cent) of low-value hull, is of low density and is difficult to handle. Many countries are equipped to use it locally, either in the natural state for animal feeding, or separated into oil and cake.

Producing countries wishing to export prefer to sell oil and cake, so as to avoid high transport costs for a merchandise which contains only 50 per cent useful material.

Table 24 shows the main exporting and importing countries in 1976.

39/ Copra is also richer in oil, but is rather a different case.

Table 24. Main cotton-seed exporting and importing countries in 1976

Exporting country	Seed exports	
	Thousand tons	Percentage
World	227.3	100.0
Africa:	63.4	27.9
Mali	16.0	7.0
Ivory Coast	11.4	5.0
Chad	10.0	4.4
America:	96.3	42.4
United States	64.8	28.5
Nicaragua	31.2	13.7
Asia	14.6	6.4
Europe	2.4	1.0
USSR	49.8	21.9
Oceania and Australia	0.8	0.4

Importing country	Seed imports	
	Thousand tons	Percentage
World	236.3	100.0
Africa	0.5	0.2
America:	70.6	29.9
Mexico	64.1	
Asia:	117.1	49.6
Japan	95.0	
Lebanon	22.0	
Europe:	48.1	20.3
Greece	46.0	
USSR, Oceania and Australia	0	0

Source: FAO Trade Yearbook, 1976, Rome, 1977.

D. Movement of cotton-seed prices

The price of cotton-seed depends on the characteristics and quality of the seed, the terms of sale (production price, wholesale price, import prices f.o.b. or c.i.f.), and the countries concerned. If the prices are all converted into dollars per ton, it must be borne in mind that the exchange rate varies.

All the following figures are taken from FAO documents, particularly the Monthly Bulletin of Agricultural Economics and Statistics.

1. Production price

   In Egypt: 44-49 $/ton from 1975 to 1977 40/

   In the United States: 75-145 $/ton from 1975 to 1977

2. Wholesale price

   In India: 109-216 $/ton from 1975 to 1977

3. Import price

   In Japan, for cotton-seed from former French West Africa: 163-256 $/ton c.i.f. from 1975 to 1977

   In Europe (Antwerp, Rotterdam): for cotton-seed from Sudan, c.i.f.:

Year	1972	1973	1974	1975
Dollars/ton	106	153	230	219

As a comparison, the FAO Monthly Bulletin gives the following price ranges for soya beans for the period 1 January 1975 to 31 December 1977:

For the United States producer, 157-338 $/ton

For the United Kingdom importer, c.i.f. United Kingdom, 186-393 $/ton.

This shows the price difference in favour of soya bean.

E. Mode of delivery and transport costs

Transport costs are an important element of the final price of cotton-seed.

When, as frequently happens, the seed must be carried by sea, it may be carried in two ways: in bulk in the hold, or in containers.

40/ "From 1975 to 1977" means that prices were analysed month by month during the three years but only the highest and lowest values are given.

Container transport avoids bulk-breaking on loading and unloading, and protects seed quality better. When quantities permit, however, it is more economical to carry cotton-seed in bottoms of 2,500 to 3,000 tons. Costs may be reduced further by grouping shipments so as to permit the chartering of bottoms of 10,000 tons.

Table 25 shows the cost elements in 1978 for shipments from the Ivory Coast and India to a French port. They are based on current conference[41/] rates.

Table 25. Cotton-seed shipment costs (dollars/ton)

From	To	Packing	Basic freight cost	Supplements	Total
India	France	Containers	70	30	100
Ivory Coast	France	Bulk (2,500-3,000 tons)	24	8	32
Ivory Coast	France	Bulk (10,000 tons or more)	20	7	27

Sources: Compagnie générale maritime.
Burry Rogliano Salles.

It can be seen that container, or even bag, shipment is possible for small quantities.[42/] The costs are far higher than for bulk shipment, so the latter is more frequently employed.

F. Quality standards

The definition of cotton-seed quality standards has been much studied since the beginning of the twentieth century.

In the United States, "grade" is determined by multiplying a quantity index by a quality index, and dividing the result by 100.

41/ "Conference" means the group of shipping companies serving the same regular lines. There are, for example, two conferences between the eastern coast of the United States and the northern European ports. Shipping traffic is thus distributed in several "conferences" within which the companies agree on identical freight rates.

42/ Containers 20 or 40 feet long (27 and 54 m^3 useful capacity respectively) may be used.

The quantity index

The quantity index can be calculated by the following formula:

$$i = 4_{P1} + 6_{P2} + _{P3} + 5$$

where:

P1 = percentage of oil

P2 = percentage of ammonia

P3 = correction for the percentage of linters

P3 is determined as follows:

Percentage linters on seed	Correction
10.6 and higher	premium = (percentage linters -10.5) x 1.0
10.5	None
10.4 to 9.0	rebate = (10.5 -percentage linters) x 1.0
8.9 to 4.0	rebate = [(9.0 -percentage linters) x 2.0] + 1.5
3.9 to 0	rebate = [(4.0 -percentage linters) x 2.5] + 11.5

The quality index

Prime quality cotton-seed

Prime quality cotton-seed is cotton-seed containing less than 1 per cent extraneous material, 12 per cent moisture, and 1.8 per cent free fatty acids. It is allocated a quality index of 100.

"Below prime quality" cotton-seed

When the above-mentioned figures are exceeded, the quality index is reduced as follows:

A deduction of 0.4 for each 0.1 per cent of free fatty acid over 1.8 per cent;

A deduction of 0.1 for each 0.1 per cent of extraneous material above 1 per cent;

A deduction of 0.1 for each 0.1 per cent of moisture above 12 per cent.

"Off-quality" cotton-seed

Off-quality cotton-seed is cotton-seed that has gone through processes other than the usual ones (cleaning, dehydration, ginning, sterilization), hot or fermented seed, or seed containing more than 12.5 per cent free fatty acids, 10 per cent extraneous material, 20.2 per cent moisture, or 25 per cent moisture and extraneous material combined.

"Below grade" cotton-seed

When the grade, calculated as indicated above, is below 40, the seed is designated "below grade", and no grade is indicated to the buyer.

The United States grading given above dates from 1963. It is rather complicated and presupposes that sampling is done correctly. It has the advantage, however, of providing a reference scale based on many factors which faithfully reflects the future oil and cake yields.

Other countries, such as India, use other systems of classification.

IX. THE COTTON-SEED OIL MARKET

A. World production

World production of cotton-seed oil averages just over 3 million tons (table 26).

Table 26. World cotton-seed oil production

	1972	1973	1974	1975	1976	1977 (provisional figures)
World cotton-seed oil production (million tons)	2.79	3.01	3.15	3.30	2.83	3.76
Percentage of world cotton-seed production	11.3	12.1	12.2	14.4	12.0	-

As the average oil content of cotton-seed is 19 per cent, it can be seen that only some 65 per cent of the seed tonnage is used for oil extraction.

Tables 27 and 28 permit a comparison of cotton-seed oil production with that of other fats. Table 27 shows that between 1973 and 1977 (provisional figures), cotton-seed oil accounted for 6-8 per cent of world edible and non-edible fats production.

Table 27. World cotton-seed oil production compared with total fats production

	1972	1973	1974	1975	1976	1977 (provisional figures)
World cotton-seed oil production, as a percentage of total world fat production	7.1	6.7	7.2	7.2	5.9	7.8

The comparison also shows that world cotton-seed oil production lies far behind that of soya oil, a little behind that of sunflower oil, and on the same level as that of groundnut oil. There is also a steady rise of palm-derived oils (palm oil extracted from the fruit pulp, palm-kernel oil extracted from the kernel; world tonnage of the former is six times that of the latter).

Crude cotton-seed oil production in the United States, from 1974 to 1976 was as follows:

	1974	1975	1976
Crude cotton-seed oil production (million tons)	0.686	0.551	0.446

Table 28. Annual world oils and fats production, 1973-1976, and forecast for 1977 (million tons)

Raw material	1973	1974	1975	1976	1977 (provisional figures)
Soya	7.38	9.30	8.27	10.10	9.53
Sunflower	3.58	4.51	3.97	3.56	4.17
Colza	2.41	2.37	2.50	2.47	2.43
Palm	2.25	2.61	2.94	3.23	3.58
Fish	0.80	1.00	0.97	0.91	0.99
Groundnut	2.91	3.05	3.01	3.45	3.28
Lard	4.26	4.46	4.33	4.30	4.50
Lauraceae a/	2.95	2.69	3.27	3.53	3.36
Cotton-seed	3.01	3.15	3.30	2.83	3.76
Other edible products b/	7.17	7.22	7.09	7.57	6.66
Tallow and fats	4.43	4.92	4.70	4.70	4.80
Other non-edible products c/	1.51	1.67	1.50	1.52	1.45
Total	42.66	46.95	45.85	48.17	48.51
United States	10.64	12.34	10.18	11.50	10.83
Other countries	32.02	34.61	35.67	36.67	37.68

Source: National Renderers Association, 1976.

a/ Coconut, palm scrap and babassou oils.

b/ Sesame, safflower, maize, olive, butter and whale oils.

c/ Castor and linseed oils, oiticic oil, tungsten oil, olive and sperm oil residues.

B. International trade in cotton-seed oil

Cotton-seed oil is mainly consumed in the producing countries; only 10 per cent of world production, or an average of 300,000 tons a year, is traded internationally. The United States is the main exporter: in 1976, for example, of a world exported total of 280,000 tons, the United States accounted for 244,000 tons. The main importers in 1976 were Egypt (138,000 tons), Venezuela (27,000 tons), Iran (20,000 tons), Japan (13,000 tons), and Turkey (11,500 tons).

It is interesting to compare international trade in cotton-seed oil with trade in other edible vegetable oils (see table 29).

Table 29. World trade in various oils in 1975

Edible vegetable oil from:	World exports in 1975: Thousand tons	World exports in 1975: As percentage
Soya	1,364	21.1
Palm	2,046	31.6
Copra	1,031	16.0
	405	6.3
Cotton-seed	375	5.8
Sunflower	624	9.6
Palm-kernel	259	4.0
Colza	353	5.4
Sesame	3	-
Other	8	-
Total	6,468	100.0

Table 29 shows that cotton-seed oil does not play an important part (some 6 per cent) in international trade in vegetable oils.

Soya and palm oil together account for 53 per cent of world edible vegetable oil exports, and it is estimated that the figure could rise to 67 per cent in 1990. The economic needs and stimuli combine to develop soya cultivation throughout the world. The United States still dominates the market, but areas under cultivation are rapidly increasing in Brazil and Argentina.

The main contribution to the rise in edible oil resources, however, will be palm oil. World exports are already 2 million tons, which is an increase of four times in the last ten years. Malaysia has been chiefly responsible for the increase. Production there in 1967 was 200,000 tons and is now 1,500,000 tons. Malaysia expects to be producing 5,500,000 tons by 1990. Other countries are also developing their production, especially the Ivory Coast and Indonesia. Allowance must also be made for palm trees planted throughout the world which have not yet reached fruit-bearing age, or are not yet giving maximum yield. These trees will probably offer an additional one million tons of palm oil in the next three or four years - an increase of 30 per cent.

As a result, the share of cotton-seed oil in world vegetable oil production will fall, as will its already tiny share of exports. Another consequence, which affects all oilseeds, is that a reduction[43/] in oil prices is expected.

C. The price of cotton-seed oil

Crude oil

According to FAO, the average wholesale price of crude oil, in tank cars, f.o.b. Valley Points (United States), was $600/ton in 1975, $514/ton in 1976, and $578/ton from January to September 1977.

Semi-refined oil

The cotton-seed oils traded internationally are always semi-refined, and correspond to the prime bleachable summer yellow grade, which is a first-grade neutralized oil intended for bleaching. A definition was given in chapter V.

Table 30 permits a comparison of prices (c.i.f. Europe) for various oils between 1960 and 1976.

International trade prices for cotton-seed oil are very similar to or slightly below those of groundnut oil, almost the same as those of sunflower oil (except from 1966 to 1969), and substantially higher than those of soya oil. But the price differences vary in absolute and relative values, since oil prices are very sensitive to all the factors that affect the supply and demand ratio, particularly climatic conditions, which affect harvests, and also currency fluctuations and speculation.

43/ In real value, after correction for inflation.

A comparative study of price chart lines shows that there is a correlation between the different oils.

Cotton-seed oil traded inside the producing countries is usually crude or neutralized oil (India).

International and domestic trade is thus mainly in semi-refined cotton-seed oils. The reason for this is that crude oil has to be neutralized very quickly, since otherwise the coloured pigments may fix irreversibly; this happens within a few days or weeks, so it is inadvisable to store or transport crude oil for long periods.

Table 30. Comparative prices of various vegetable oils 1960-1976
(dollars/ton, c.i.f. Europe)

Year	Soya a/	Sunflower b/	Cotton-seed c/	Groundnut d/	Colza e/	Olive f/	Palm g/	Copra h/	Palm-kernel i/
1960	225	243	235	326	219	585	228	312	317
1961	287	311	305	331	280	561	232	254	263
1962	227	246	266	275	221	631	216	251	255
1963	223	236	243	268	215	871	222	286	287
1964	205	255	250	315	252	586	240	297	299
1965	270	294	278	324	263	663	273	348	353
1966	261	263	333	296	244	661	236	324	271
1967	216	212	378	283	206	690	224	328	249
1968	178	172	305	271	161	681	169	399	367
1969	228	213	291	332	200	666	181	361	306
1970	307	331	354	379	293	699	260	397	429
1971	323	375	392	441	295	727	261	371	335
1972	270	326	324	426	232	916	217	234	244
1973	465	480	500	546	395	1,399	378	513	491
1974	795	983	939	1,077	745	2,174	669	998	1 010
1975	619	739	726	857	551	2,436	433	393	439
1976	376	600	645	675	390	2,350	370	340	360

a/ Crude, United States, c.i.f. Rotterdam.
b/ Any origin, ex-tanker Rotterdam.
c/ Prime bleachable summer yellow, United States, c.i.f. Rotterdam.
d/ Nigeria, Gambia, any origin, c.i.f. Europe.
e/ Netherlands, f.o.b. ex-mill.
f/ Spain, edible.
g/ Malaysia, c.i.f. United Kingdom.
h/ Philippines, Indonesia, in bulk, c.i.f. Rotterdam.
i/ Western Africa, c.i.f. United Kingdom.

D. Effect of transport costs depending on mode of delivery

For small quantities, oil may be shipped in containers, but shipment is usually by special tankers. Table 31 gives some examples of costs.

Table 31. Cotton-seed oil transport costs[a/]
(dollars/ton)

From	To	Packing	Basic freight cost	Supplements	Total
India	France	In tank	65	25	90
United States (East Coast)	France	In containers	180	28	208

Sources: Compagnie générale maritime.
Barry Rogliano Sallee.

a/ Conference rates.

It can be seen that tanker transport is much cheaper, particularly since even better terms may sometimes be obtained.

E. Quality standards

The quality standards to be met by cotton-seed oil are listed in chapter V.A.

F. Trade practice

On domestic markets, millers often sell to refiners and margarine manufacturers directly or through brokers.

On international markets, it is the large commercial firms and brokers of the main centres who trade. Some of the trade flow is connected with special export regulations in the United States.

X. THE COTTON-SEED CAKE MARKET

A. World production

Table 32 shows the production of the main producing countries in 1974-1976 (in thousand tons of cake).

Table 32. Cotton-seed cake production 1974-1976

	1974	1975	1976
USSR	1 600/1 800	1 800/2 000	1 600/1 800
United States	1 910	1 510	1 230
China	900/1 100	900/1 100	1 000/1 200
India	900/1 000	900/1 000	900/1 000
Pakistan	500/ 600	450/ 600	300/ 400
Brazil	400/ 500	350/ 450	300/ 400
Turkey	300/ 400	300/ 400	200/ 400
Mexico	200/ 300	200/ 300	100/ 200
Argentina	50/ 100	100/ 200	90/ 150
Approximate total	7 235	7 035	6 250

Source: C. Robert, 1977.

The table is incomplete, however, since it omits several countries whose production is not negligible: Colombia, Egypt, Guatemala, Nicaragua, Paraguay, and the Sudan.

Table 33 permits a comparison of world production of various cakes, expressed in thousands of tons of protein.

The table shows the dominant position of soya cake, but cotton-seed cake comes second, and accounts for about 13 per cent of total production.

It is interesting to note that, world cotton-seed production having averaged 24.6 million tons in the period 1973-1975, if it is assumed that the protein content is about 21 per cent, the potential protein tonnage is 5.2 million. Since cake production is equivalent to 3,660,000 tons of protein, it appears from this rough calculation that only 70 per cent of world cotton-seed tonnage goes to produce cake. As was seen in chapter IX.A., a similar reasoning applied to oil led to a proportion of 65 per cent, which is quite comparable, as could be expected.

Table 33. World production of various cakes

Cake	Cake protein production (average value 1973-1975)	
	Thousand tons	As percentage
Soya	17 270	63.7
Cotton	3 660	13.5
Groundnut	1 990	7.3
Sunflower	1 630	6.0
Colza	1 340	5.0
Linseed	470	1.7
Copra	280	1.0
Miscellaneous	490	1.8
Total	27 130	100.0

Source: FAO statistics.

B. International trade in cotton-seed cake

Cotton-seed cake is traded in far larger amounts than cotton-seed and cotton-seed oil. The figures for 1972-1976 were as follows:

	1972	1973	1974	1975	1976
Total exports of cotton-seed cake (thousand tons)	1 419	1 428	1 071	1 088	894

Table 34 shows the main exporting and importing countries in 1974, 1975 and 1976.

It will be noted that the flow of imports is almost entirely to Europe, with Denmark as the major importer, followed by the Federal Republic of Germany.

The exporting countries are distributed more evenly across the world and are to be found in Africa, America and Asia.44/ The main exporters are India and Turkey, followed by the Sudan and Argentina.

44/ There are even some European countries, Greece for example, which import and process seeds, consume oil, and export cake.

Table 34. Statistics of international trade in cotton-seed cake

	1974		1975		1976	
	Thousand tons	As percentage	Thousand tons	As percentage	Thousand tons	As percentage
			Exports			
Africa	215	20.1	250.6	23.0	217.2	24.3
Egypt	(23.5)		(38.2)		(17.0)	
Ethiopia	(19.8)		(13.0)		(14.4)	
Mozambique	(22.8)		(18.4)		(13.0)	
Sudan	(55.8)		(93.7)		(100)	
Uganda	(26.6)		(16.1)		(16.2)	
United Republic of Tanzania	(39.7)		(43.3)		(28.8)	
America	363.3	33.9	289.6	26.6	310	34.7
Argentina	(24.2)		(59.2)		(95)	
Brazil	(86.2)		(19.1)		(3.5)	
Colombia	(29)		(60.4)		(44)	
Guatemala	(61.5)		(27.7)		(35)	
Nicaragua	(73.7)		(70.4)		(60)	
Paraguay	(18.5)		(20.6)		(28)	
United States	(44.6)		(14.4)		(29.5)	
Asia	386.5	36.1	444.2	40.8	262.6	29.4
India	(145.9)		(192.4)		(130)	
Iran	(43.2)					
Pakistan	(14.7)		(12.5)		(30.1)	
Turkey	(152)		(217.8)		(88.9)	
Europe	95.8	8.9	98.8	9.1	104	11.6
Denmark	(16.9)		(15.7)		(8.9)	
Germany, Federal Republic of	(0.6)		(0.9)		(12.9)	
Greece	(60.8)		(75.4)		(63.0)	
Italy	(11.4)		(4.3)		(0.07)	
Netherlands	(0.3)		(0.2)		(10.6)	
Union of Soviet Socialist Republics	10	1.0	5	0.5		
Total world	1,071	100.0	1,088	100.0	894	100.0
			Imports			
Africa	14.7	1.5	14.4	1.4	14.8	1.7
Rhodesia	(11.2)		(11.8)		(12.4)	
America	6	0.6	2.8	0.2	14	6.1
United States	(3.1)		(0.6)		(12)	
Asia	5.4	0.6	5	0.5	-	
Europe	946.7	97.3	1,024	97.9	850	96.7
Denmark	(372.2)		(500)		(433.6)	
German Democratic Republic	(46)		(58)		(30)	
Germany, Federal Republic of	(160.7)		(178.6)		(170.4)	
Ireland	(4.8)		(7.5)		(17)	
Netherlands	(3.1)		(2.8)		(11.4)	
Norway	(26.8)		(20.8)		(20.8)	
Poland	(46.7)		(70)		(50)	
Sweden	(64.5)		(71)		(56.3)	
United Kingdom	(68.5)		(34.7)		(32.5)	
Union of Soviet Socialist Republics	-	-	-	-	-	-
Total world	973	100.0	1,046	100.0	879	100.0

Source: FAO Trade Yearbook, 1976, Rome 1977.

Table 35 showe the position of international trade in cotton-seed cake in relation to trade in other cakes.

Table 35. World exports of various cakes

Cake	World exports of cake in 1975	
	Thousand tons	As percentage
Soya	8 745	68.8
Groundnut	1 158	9.1
Cotton	1 115	8.8
Copra	697	5.5
Sunflower	358	2.8
Colza	272	2.1
Palm kernel	374	2.9
Total	12 719	100.0

Cotton-seed cake occupiee third place in international trade, far behind soya cake, but almost on a par with groundnut cake.

In practice, trade between cake producing and consuming countriee are often an extension of traditional flows: France, for example, continues to import considerable amounte of groundnut cake, because it started to do so regularly at the time when its colonies covered a large part of Western Africa, but it imports very little cotton seed and cake.

C. Cotton-seed cake prices

Wholesale prices

The monthly bulletins of agricultural económics and statistics quote separate wholesale prices for cotton-seed cake and cotton-seed meal, i.e. press-extracted cake and solvent-extracted meat.

The average price on the Copenhagen exohange for Danieh 46 per cent protein cotton-seed cake wae:

Year	Dollars/ton
1975	174
1976	214
1978 (January to Auguet)	247

United States 41 per cent protein cotton-seed meal was sold in bulk in Memphis (Tennessee) at an average price of:

Year	Dollars/ton
1975	131
1976	175
1978 (January to July)	212

Import prices

The same FAO monthly bulletins indicate the average prices c.i.f. Liverpool for 43 per cent protein cotton-seed cake from any origin as:

Year	Dollars/ton
1975	172
1976	207
1977 (January to July)	255

"Oil World Semi-Annual" gives the average price c.i.f. Hamburg of a 45-46 per cent protein cotton-seed cake for 1975 as 153 dollars/ton.

Comparison with other cakes

It is interesting to compare the wholesale prices (taken from the FAO monthly bulletins) for a cotton-seed meal and a soya-bean meal, both sold in bulk, in the United States (see table 36).

Table 36. Comparison of cotton-seed cake and groundnut cake wholesale prices in the United States

	Average 1975	Average 1976	Average from January to July 1977
		(dollars/ton)	
Cotton-seed cake (41% protein)	131	175	212
Soya-bean cake (44% protein)	147	190	258

The comparison confirms the slight price advantage in favour of soya cake.

The prices for ground-nut cake are usually about the same as those for cotton-seed cake.

D. Effect of transport costs[45] depending on mode of delivery

Because of the large quantities involved, cake is almost always shipped in bulk, in special holds (tanks). For a delivery from India to France, the cost is 27-32 dollars a ton, including supplements. The cake is loaded and unloaded by special high-capacity handling equipment which eliminates almost all human labour.

Bags and containers are little used. They are suitable only for small tonnages and are costly. As an example, for a container delivery from India to France, the transport cost, including supplements, is 100 dollars/ton.

During transport, care must be taken that the cakes are not remoistened to above their normal moisture content, or re-contaminated by moulds, micro-organisms, insects, rodent excrement, etc.

E. Quality standards

The quality standards for cotton-seed cake are given in chapter VI.A.

F. The importance of cake in the profitable exploitation of the constituents of cotton-seed

Table 20 shows the importance of cake in relation to the other cotton-seed by-products.

G. Trade practice

International trade is usually through international trading firms, commercial brokers and distributors who work directly with the animal feed manufacturers.

In some seed and cake producing countries, exports are strictly regulated by the Government. Trade may be the responsibility of a State monopoly, or may be left to the initiative of trading firms, subject to legal stipulations that may, as an example, set quotas.

45/ The sources used are, as for the carriage of oil and seed, the Compagnie générale maritime and Burry Rogliano Salles.

H. The developing countries

As is the case of ground-nut cake, transport costs from the producing countries to the main European consuming countries are fairly high in relation to the value of the product. It would therefore be in the interest of the producing countries if they could sell their output locally, except that in most developing countries there are virtually no animal feed industries, since there is no market based on intensive breeding. There is very little local demand, therefore, and the unexported cake is either fed as it is to the cattle, or simply destroyed.

The development of the domestic market for cake in those areas depends, therefore, on stock-breeding development, which depends in turn on local meat consumption habits. Generally speaking, breeding is extensive and, despite the efforts of some Governments, it is still a long way to the industrial threshold that would coincide with a rapid rise in demand for cake.

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