methyl group. Of particular interest was that, in addition to these signals, the spectrum accompany relatively weak signals at slightly lower field (0.1-0.4 ppm) of 28.7, 135.9, 43.0, 33.2, and 17.9 ppm (see Fig. 1) and the chemical shifts were in complete accord with the corresponding signals for the 24α-methyl epimer, *trans*-22-dehydrocampesterol acetate (9). The ^{13}C NMR spectra for the C_{28} $\Delta^{5,22}$-steryl acetates separated from 7 different seed oils were also basically the same as that from brown mustard. It is noticed here that, although the chemical shift differences of the C-26 and C-27 carbons between the C-24 epimeric pair were also observed in each spectrum, the C-27 signal in 24β-isomer and the C-26 signal in 24α-counterpart overlapped each other. All the C_{28} $\Delta^{5,22}$-steryl acetates separated from eight Brassica seed oils were, therefore, regarded as a C-24 epimeric mixture.

Table III shows the relative intensities of the C-16, C-22, C-24, C-25, and C-28 signals in the mixtures. All the signals in a mixture under consideration had similar relative intensities, thus suggesting approximate proportion of the epimers. The intensity measurements established that the C_{28} $\Delta^{5,22}$-sterol fractions in Brassica oils contain ca. 10-30% of *trans*-22-dehydrocampesterol along with brassicasterol.

Nes et al. (10,11) have recently shown by 220 MHz ^{1}H NMR that 24-methylcholesterol fractions (C_{28} Δ^5-sterols) separated from a series of Tracheophytes are always C-24 epimeric mixture with the 24α-isomer presents in about twice the concentration of the 24β-isomer. The present study also demonstrated the co-occurrence of C-24 epimeric 24-methylcholesta-5,*E*-22-dien-3β-ols by ^{13}C NMR spectroscopy, though the 24β-epimer much predominant.

ACKNOWLEDGMENTS

Sakai Spice Industry Co. provided mustard seed samples. T. Ishikawa made ^{13}C NMR spectral measurements. T. Shigemoto, S. Ishii and H. Tamura provided technical assistance.

REFERENCES

1. Appelqvist, L.-Å, in The Biology and Chemistry of the Cruciferae, edited by J.G. Vanghan, A.J. MacLeod and B.M.G. Jones, Academic Press, London, 1976, p. 221.
2. Appelqvist, L.-Å, JAOCS 48:851 (1971).
3. Fedeli, E., A. Lanzani, P. Capella and G. Jacini, Ibid. 43:254 (1966).
4. Homberg, E.E., Phytochem. 15:129 (1974).
5. Knights, B.A., and A.M.M. Berrie, Ibid. 10:131 (1971).
6. Ingram, D.S., B.A. Knights, I.J. McEvoy and P. Mckay, Ibid. 7:1241 (1968).
7. Seher, A., and E.E. Homberg, Proc. 4th Int. Congr. Rapeseed, ed. Deutsche Gesellschaft für Fettforschüng, Münster, 1974, p. 301.
8. Itoh, T., T. Tamura and T. Matsumoto, Fette, Seifen, Anstrichm. 80:382 (1978).
9. Wright, J.L.C., A.G. McInnes, S. Shimizu, D.G. Smith, J.A. Walter, D. Idler and W. Khalil, Can. J. Chem. 56:1898 (1978).
10. Nes, W.R., K. Krevitz, J. Joseph, W.D. Nes, B. Harris, G.F. Gibbons and G.W. Patterson, Lipids 12:511 (1977).
11. McKean, M.L., and W.R. Nes, Phytochem. 16:683 (1977).

[Received April 5, 1982]

An Investvation of the Extraction, Refining and Composition of Oil from Winged Bean (*Psophocarpus tetragonolobus* [L.] D.C.)

D. BODGER, J. B. DAVIS, D. FARMERY[1], T. W. HAMMONDS, A. J. HARPER[1], R. V. HARRIS, L. HEBB[1], N. MacFARLANE, P. SHANKS[1] and K. SOUTHWELL,
Tropical Products Institute, 56/62 Gray's Inn Road, London WC1X 8LU, England; and [1]Simon-Rosedowns Ltd., Cannon Street, Hull, England

ABSTRACT

Eleven winged bean accessions from Thailand were analyzed. Oil content ranged between 15 and 18%. Oleic and linoleic acids were the major fatty acids (62.5-64.5%) together with behenic (12.6-14.4%) and lignoceric acid (2.4-2.8%). Linolenic acid level was low and traces of 15-, 17- and 21-carbon acids (saturated and unsaturated) were found. No parinaric acid was detected. Campesterol, stigmasterol and β-sitosterol were the principal components of the unsaponifiable fraction. The extracted oil had a very low free fatty acid (FFA) content but was not completely liquid below 35 C. The refining of crude winged bean oil is reported. Oil produced by expeller had a strong, beany aroma but a negligible level of gums and a low level of FFA. Degumming and neutralizing were unnecessary; bleaching produced an attractive colored oil free from beany aroma. Crude solvent-extracted oils from whole and decorticated winged beans had appreciable contents of gums and higher FFA contents than expeller-produced oil. Laboratory refining demonstrated the strong interference on bleaching exerted by gums and FFA. Conventional refining by degumming, neutralizing, bleaching and deodorizing, and by physical refining produced high-quality oils having a good color, low FFA level and no taste or smell. The solid/liquid ratio of refined winged bean oil as a function of temperature was found to be unusual. Oil was extracted from whole and decorticated winged beans in a pilot solvent extraction plant designed to simulate a Rotocel. Winged bean flakes were not as mechanically strong as those from soybean but good oil extraction yields were obtained and a meal was produced having an oil content of less than 1% at 10% moisture. Whole winged beans were expelled in a small expeller (throughput 16.8 kg/hr). Cake was produced with a residual oil content of 3.3-5% in a single pass through the expeller.

INTRODUCTION

The winged bean (*Psophocarpus tetragonolobus* [L.] D.C.) is a leguminous plant native to tropical Asia and grown there on a small scale for its seeds, immature pods and roots, all of which are used for food. The seeds are rich in protein (30-38%) and also contain oil (15-20%). The oil is said to resemble soybean (1) and groundnut (2) oils.

The potential of the winged bean has been noted (3-6) and it is at present the subject of considerable scientific interest in many tropical countries. The Tropical Products Institute has undertaken a detailed postharvest evaluation of the winged bean and this paper reports findings on the oil content and composition of 11 winged bean accessions from Thailand, extraction of oil by expeller and pilot-scale solvent extraction plant and refining of the oil.

EXPERIMENTAL PROCEDURES

Materials

The 11 winged bean accessions were air-freighted from Thailand to the U.K. immediately after harvest. The seeds received were clean and reasonably free of twigs, pod fragments and similar plant debris. No insects were observed and no insect damage was noted in 10 of the 11 accessions. A small proportion (0.1%) of the seeds of accession "Raburi white" showed signs of insect attack.

Oil Contents and Moisture Contents

These were determined by oven drying and solvent extraction according to British Standards (7). Additionally, oil content of moisture-free beans was measured by the nuclear magnetic resonance (NMR) technique using a Newport Quantity Analyser (8). Crude winged bean oil was used as standard reference and all measurements were made at 45 C.

Fatty Acid Composition of the Oils

Beans were milled (Apex knife mill) and then ground with aromatic-free petroleum spirits (bp 40-60 C) first with a top-drive macerator and then with a Silverson grinder. Extracts were filtered and concentrated under reduced pressure in a rotary evaporator at 50-60 C. Traces of solvent were removed in a vacuum oven at 52-59 C/40 mm Hg (9).

Methyl esters of the fatty acids of the oils were prepared using 1% sodium methoxide in methanol. The major fatty acid composition was determined by gas liquid chromatography (GLC) using nitrogen (50-60 mL/min) as carrier gas and the following conditions: (a) 180 C—6 ft column packed with Carbosorb (WHP 100-120 mesh) coated with 10% diethylene glycol succinate (DEGS); Varian Aerograph 2100, flame ionization detector; and (b) 224 C—5-ft column packed with Gas Chrom Q (80-100 mesh) coated with 3% Apiezon 'L'; Pye 105, flame ionization detector. Unsaponifiables, iodine and saponification values of extracted oils were determined by the British Standard method (10).

Preliminary Examination of Unsaponifiable Fractions

The unsaponifiable fraction was obtained by a modification of the procedure used by Davis et al. (11). Oil (5 g) was dissolved in ethanol (44 mL) and petroleum ether (bp 30-40 C) (10 mL) and freshly prepared, cooled potassium hydroxide solution (5 g in 8.5 ml water) were added, then the mixture was shaken and allowed to stand for 24 hrs. Distilled water (1 vol) and diethyl ether (1/2 vol) were added and the upper layer was collected in a separating funnel. The lower, aqueous layer was extracted twice with ether (30 mL). The combined ether extracts were washed four times with water (30 mL), dried with ether-washed sodium sulfate and evaporated under reduced pressure at 20 C to leave a yellow oil, which crystallized upon standing into rosettes of white needles (yield ca. 30 mg). This material, dissolved in ether (2 mL), was subjected to GLC on a Pye 105 gas chromatograph equipped with a flame ionization detector using a 1-m column of 1% OV17 on Chromosorb W-AW-DMCS (silanized) with 45 mL/min nitrogen as carrier. Analyses were conducted at three temperature regimes: (a) programmed, 8 mins at 50 C; increase of 8 C/min to 230 C; hold; (b) 230 C isothermally; (c) 320 C isothermally.

The identity of peaks was confirmed by comparing the retention times with those of authentic specimens and by showing no separation upon admixture and/or by sampling the peak from GLC on a VG-Micromass 7070-F mass spectrometer running at 70 EV in the electron impact mode measuring molecular weights.

Decortication

Whole beans were boiled in water for 3 hrs. Those which remained small and hard were separated by screening or brine flotation, washed free of salt and then autoclaved at 120 C for 1 hr. The treated beans were milled in a disc mill running at 300 rpm, with an output of 40 kg/hr, followed by drying to a moisture content of 5%. The hulls and meats were separated by air elutriation.

Pilot Plant Preparation and Solvent Extraction

Using the pretreatment method for soybeans as a basis, representative samples of whole and decorticated beans were prepared for solvent extraction as follows: (a) cracking—the beans were reduced to quarters by passing through a pair of fluted rolls having a gap clearance of 3.5 mm; (b) conditioning—the cracked beans were heated to 75 C and held at this temperature for 30 min. The moisture content of decorticated beans was raised by live steam injection; and (c) flaking—the cracked/conditioned beans were flaked by passing through a pair of flaking rolls. Conditions are recorded in Table I.

A simulated Rotocel extraction test devised by Simon-Rosedowns was used. Each run used a charge of seed flakes of ca. 16 kg contained in a glass column of 3-m bed depth. Precise conditions are recorded in Table I. Desolventization of the extracted meal was performed in a single-stage desolventizer using live steam and dry heat to remove the solvent.

Recovery of oil from the miscella extracts was carried out by an initial evaporation to concentrate the oil to ca. 90% (w/w) in an atmospheric evaporator, followed by steam stripping under vacuum to remove final traces of solvent.

Oil Expelling

Oil was expressed using the Hander "New Type 52" expeller (Hander Machinery Oil Co., Osaka, Japan) powered by a 2.2-kW, 3-phase motor. Before the expulsion of whole beans, the expeller cage and barrel were heated to 90 C by passing an oil cake through. The choke was adjusted to produce a cake thickness of ca. 1 mm.

Laboratory Refining

The oils were treated with 5% w/w water at 70 C with slow stirring for 15 min; subsequent centrifuging removed gums without difficulty. Caustic neutralization was carried out using 8° Baume sodium hydroxide in 100% excess (twice the stoichiometric amount) at 40 C with slow stirring. Upon addition of lye, the oil temperature was raised to 60 C and maintained at this temperature overnight, during which time the soap stock settled. The clear oil was removed by siphoning. The proprietory bleaching earths Tonsil 60 (Süd Chemie A.G., München), Tonsil Standard FF and Fulmont 237 (The Fullers' Earth Union Limited, Surrey) were added separately to aliquots of oil at levels of 0.5, 1.0 and 2.0% for 1 min at 104 C in an open beaker, stirred and then filtered. The oils were not deodorized.

Commercial Refining

Caustic neutralization. The crude oil obtained by solvent extraction of whole winged beans was degummed using 0.05% concentrated phosphoric acid after first deaerating and drying (80 C, 2 hr at 10 mm Hg) the oil. After addition of phosphoric acid, oil was subjected to reduced pressure (60 mm Hg), and its temperature was raised to 70 C

TABLE I

Pilot Plant Solvent Extraction Data

	Whole winged beans	Decorticated winged beans
Whole seed analysis		
Moisture (%)	7.96	1.06
Oil (%)	14.13	20.86
Material pretreatment		
Cracking gap	3.5 mm	3.5 mm
Conditioning	Dry heat	Live steam addition
Conditioning–final temperature	75 C	75 C
Flaking gap	0.20-0.23 mm	0.13-0.15 mm
Cracked seed analysis		
Moisture (%)	7.49	4.85
Flaked seed analysis		
Moisture (%)	7.38	5.63
Oil (%)	17.45	21.30
Bulk density	359-460 kg/m^3	364-477 kg/m^3
Flake thickness	0.38-0.43 mm	0.30-0.43 mm
Extraction data		
Extraction times	5 X 10 Min miscella extraction 1 X 10 Min final solvent extraction	5 X 15 Min miscella extraction 1 X 15 Min final solvent extraction
Drain times	6 X 10 Min	5 X 10 Min 1 X 15 Min final drain
Solvent ratio (% w/w)	2:1	2:1
Column loading	18.1 kg – 2.44 m bed depth	22.7 kg – 3.30 m bed depth
Packing density	421 kg/m^3	402 kg/m^3
Solvent throughput	30,476 kg/hr/m^2	7320-9413 kg/hr/m^2
Miscella feed temperature	55-60 C	55-60 C
Desolventization data		
Desolventizing time–atmospheric	90 min	75 min
Stripping steam rate	2.7 kg/hr	3.0 kg/hr
Desolventizing time–vacuum	30 min at 89 mm Hg	20 min at 152 mm Hg
Final meal temperature	90 C	110 C
Weight of extracted meal	14.5 kg	17.2 kg
Weight of solvent recovered	8.3 kg = 36% w/w solvent hold-up	13.3 kg = 43% w/w solvent hold-up
Extracted meal analysis		
Moisture (%)	8.55	7.63
Oil (%)	0.81	0.75
Crude protein (N X 6.25%)	43.3	46.6
Bulk density	458-553 kg/m^3	458-529 kg/m^3

followed by vigorous stirring for 15 min. The vacuum was released and 4% (w/w) of distilled water was added to the oil at 70 C. Vigorous stirring was continued for a further 15 min. The oil was centrifuged, which removed gums without difficulty. Caustic neutralization was carried out using 16° Baume sodium hydroxide in 10% excess at 80 C. The oil was stirred vigorously for 5 min followed by 20 min settling time. The oil was washed free of soap using 4 X 15% (v/v) water washes, giving a pH of 7 on the final water wash. Each wash was done at 100 C for 20 min followed by settling for 15 min. The neutralized oil was bleached using 1% Tonsil "Optimum" bleaching earth at 100 C for 30 min under reduced pressure (50 mm Hg). The bleached oil was cooled to 80 C and filtered.

After bleaching, the oil was deodorized following addition of citric acid (200 ppm) as a metal scavenger. Conditions in the deodorizer were 260 C with a steam rate of 3% (w/w)/hr for 90 min under reduced pressure (3-5 mm Hg).

Physical refining. The oil was degummed, bleached and deodorized as already described except that caustic neutralization and water washing were omitted.

Solid/Liquid Ratio of Winged Bean Oil

Winged bean oil produced by expeller and refined in the laboratory was used for this study, a separate 10-g aliquot of oil being used for each temperature reading. Each aliquot was first rapidly chilled in a sealed tube for exactly 1 hr at −18 C and then allowed to equilibrate for exactly 1 hr in a water bath at the selected temperature between 5 and 40 C before the reading was made in the Newport Quantity Analyser (12). To make these measurements, it was necessary to use as control an oil which was completely liquid between 5 and 40 C. Macadamia oil was selected for this purpose.

Stability of Refined Oil Using Active Oxygen Method

The AOM test (13) was carried out on both caustic-refined and physically refined oils obtained after solvent extraction of whole beans.

RESULTS AND DISCUSSION

Oil Content and Composition of the 11 Accessions

The oil contents of the 11 accessions reduced to a dry weight basis are recorded in Table II. The average oil content measured by solvent extraction was 16.4 compared to 17.6 found by NMR. The range of oil contents recorded here is narrower at 15.0-18.1% than the range of 14.3-21.5% reported previously (16). How far the wide oil content range recorded for winged bean seeds reflects varietal differences vs how far it reflects adaptation to environment is unknown. It is, however, noteworthy that accession

TABLE II

Oil Content of Winged Bean Accessions and Fatty Acid Composition of Winged Bean Oil

Accession name	Moisture content (%)	Oil content (dry basis) (%)	NMR oil content (dry basis) (%)	C14	C16	16:1	C17	C18	18:1	18:2	C20	18:3	20:1	C22	22:1	C24
27-02	8.3	15.9	16.9	0.06	8.8	0.3	0.08	4.3	34.1	30.5	1.4	1.1	3.3	12.9	0.8	2.6
UPS-122	8.0	17.3	18.3	0.06	8.2	0.3	0.09	6.5	35.8	28.2	2.0	0.7	2.7	12.6	0.4	2.6
Raburi White	9.8	18.1	19.6	0.05	8.6	0.2	0.08	6.0	37.4	25.1	2.0	1.0	3.1	13.5	0.6	2.5
Ratchaburi Brown	8.7	16.4	17.6	0.06	8.8	0.3	0.08	4.8	39.7	29.9	1.6	1.3	3.3	13.0	0.7	2.6
Rayong Brown	7.9	16.6	17.9	0.06	9.0	0.3	0.08	5.1	33.5	29.5	1.7	1.2	3.2	13.3	0.7	2.4
12-01	7.6	16.0	17.4	0.04	8.5	0.2	0.08	4.9	34.6	27.6	1.6	1.2	3.3	14.4	0.7	2.6
14-03	8.1	15.0	16.4	0.05	8.4	0.2	0.08	5.0	34.8	27.6	1.7	1.1	3.3	14.4	0.7	2.8
21-04	8.6	15.8	17.0	0.07	8.4	0.2	0.08	5.0	35.5	29.0	1.6	1.1	3.4	12.8	0.7	2.4
26-01	8.2	16.3	17.5	0.05	8.5	0.2	0.08	4.8	34.8	29.0	1.6	0.8	3.5	13.2	0.8	2.6
28-01	8.4	15.9	16.7	0.05	8.5	0.2	0.08	4.6	34.9	29.5	1.5	1.3	3.1	13.0	0.6	2.6
46-03	8.6	17.2	17.9	0.05	8.6	0.3	0.08	4.9	34.1	28.3	1.6	1.1	3.3	14.2	0.8	2.8

"Raburi white," which consisted of cream-colored seeds, had the highest oil content of the 11 accessions; the other 10 accessions were gray, gray-green, black, brown or tan.

The fatty acid compositions of the 11 oils are given in Table II. The results are averaged from GLC columns using DEGS and Apiezon L as oleic (18:1) and linoleic (18:2) acids were better resolved on DEGS and linolenic (18:3) and eicosenoic (20:1) on Apiezon L. The 11 oils had very similar fatty acid compositions. The major fatty acids were oleic and linoleic acid which together constituted 62.5–64.5% of the total fatty acids present. Behenic acid (22:0) was present in concentrations of 12.6–14.4% and lignoceric acid (24:0) in concentrations of 2.4-2.8%. Linolenic acid (18:3) was present at a low level (0.7–1.3%) and small concentrations (0.4–0.8%) of a monounsaturated C_{22} acid were detected. There appeared to be odd-carbon-numbered saturated and unsaturated acids (C_{15}, C_{17}, C_{21}) at concentrations of 0.1% or less and traces of C_{12} and C_{23}.

The fatty acid compositions recorded here for winged bean oil are consistent with those in the literature (1,2,6) though, in the present case, the variations in composition are small. Garcia et al. (2) found total unsaturated fatty acids ranged from 53.8–68.5% (mean 62%) whereas the present data display a range of 67.4–70.1% (mean 68.5%), which is appreciably higher.

Table III gives some further characteristics of the oils extracted from the 11 accessions. A program was written and stored on a magnetic card for use with a Texas T159 programmable calculator. The fatty acid composition for each oil given using DEGS and Apiezon L columns were used as input data and output was the average fatty acid composition and theoretical iodine and saponification values. Table III shows the close agreement between the theoretical and experimental iodine and saponification values, which supports well the fatty acid composition recorded in Table II. The iodine values ranged from 80.9 to 85.2 and the low saponification values of 186-188 mg KOH/g of oil reflect the high content of longer chain-length fatty acids.

UV spectroscopy of a 1% oil solution in isooctane showed no absorbance at 278.5, 289.5, 302.5 and 317 nm, which is characteristic for parinaric acid (conjugated 18:4) and agrees with Garcia et al. (2) and Newell and Hymowitz (14). In earlier studies, Cerny et al. (15) reported that this undesirable fatty acid was present in winged bean oil.

The unsaponifiable fraction of two of the 11 winged bean oil accessions have been studied and the results are in Table IV. Not all the peaks have been characterized, but the major components have been identified as commonly occurring natural compounds. The three steriods (campesterol, stigmasterol and β-sitosterol), which are the principal components of the unsaponifiable fraction, all occur widely in plants and derived foodstuffs, including the major edible vegetable oils. This also applies to squalene, the saturated hydrocarbons (e.g., hentriacontane) and the triterpenes, cycloartenol and 24-methylenecycloartanol (11). By implication, none of the identified constituents of this fraction of the oil would normally be considered nutritionally hazardous.

The very low levels of free fatty acids (FFA) measured in the oils (Table III) are comparable with those commonly encountered in refined oils. Efficient harvesting, rapid air-freighting from Thailand to England and immediate analysis probably account for these recorded low levels of FFA and, in a normal commercial production environment, the figures would probably be somewhat higher. Nevertheless, provided the beans are stored correctly (conditions still to be determined), quality deterioration should be minimal. In this connection, the beans were received with a low

TABLE III

Some Characteristics of Winged Bean Oil

Accession name	Free fatty acid (% oleic)	Iodine value		Saponification value (mg KOH/g)		Unsaponifiable content (%)	Parinaric acid (%)	Refractive index (C)		Relative density	
		Actual	Theory	Actual	Theory			40	20	40/20	20/20
27-02	0.08	85.2	88.4	186.1	186.4	0.3	<0.001	1.4631	1.4702	0.897	0.911
UPS-122	0.07	82.9	84.0	186.8	186.3	0.4	<0.001	1.4632	1.4703	0.899	0.913
Raburi White	0.21	80.9	81.3	186.4	185.9	0.7	<0.001	1.4628	1.4699	0.899	0.913
Ratchaburi Brown	0.07	83.9	87.5	187.2	186.2	0.6	<0.001	1.4630	1.4701	0.898	0.912
Rayong Brown	0.06	83.7	86.2	186.6	186.0	0.9	<0.001	1.4631	1.4702	0.899	0.913
12-01	0.04	84.0	84.7	186.7	186.4	1.1	<0.001	1.4633	1.4704	0.899	0.913
14-03	0.06	85.4	83.9	188.0	185.5	0.9	<0.001	1.4630	1.4701	0.899	0.913
21-04	0.06	84.6	83.8	186.7	186.4	0.8	<0.001	1.4631	1.4702	0.899	0.913
26-01	0.05	84.3	83.8	186.0	184.2	0.9	<0.001	1.4630	1.4701	0.899	0.913
28-01	0.06	85.1	87.6	186.7	185.8	0.6	<0.001	1.4632	1.4703	0.900	0.914
46-03	0.08	83.4	84.6	186.6	185.6	0.6	<0.001	1.4630	1.4701	0.899	0.913

TABLE IV

Examination of Unsaponifiable Fraction of Winged Bean Oil

Identification	Accession name	
	UPS-122 (%)	46-03 (%)
Squalene	0.3	0.4
Probably $C_{31}H_{64}$ (hentriacontane)	2	0.8
Probably $C_{32}H_{66}$ (dotriacontane)	2	0.6
Campesterol	5.6	6.0
Stigmasterol	33.7	37.8
β-Sitosterol	42.0	40.5
Probably cycloartenol	2	2
Probably (24-methylenecycloarthanol)	4.2	6.0
Unidentified compounds (5)	6.0	5.9

moisture content and have a tough seed coat which, unlike soy, does not loosen upon drying. They appear to be fairly resistant to mechanical handling damage so it seems reasonable to suppose that good storage and handling practices can be achieved with the result that a high-quality edible oil will be produced.

Winged bean oil has been reported as being similar to and readily substitutable for soybean and groundnut oils (1,2). The work reported here, however, shows that oil extracted from winged beans grown in Thailand has a considerably higher level (28-35%) of saturated fatty acids than has soybean oil (10-18%) in agreement with Newell and Hymowitz (14). Difficulty was experienced in working with winged bean oil at 20 C, at which temperature it tended to form a semisolid. At 25 C, it was liquid but had an unattractive haze. The oil did not have a bright, filter-polished appearance below 35 C. The oil may well have a small proportion (below 2%) of a glyceride having a high melting point which would have to be removed to produce an attractive liquid oil at 20-25 C.

Pilot Plant Solvent Extraction

The conditions used and yields from solvent extraction are recorded in Table I for whole and decorticated winged beans. The initial oil content of the decorticated beans was 21.1% on a moisture-free basis. This is higher than that for the whole beans (15.2%) because seed coats removed by decortication have a low oil content.

The flakes produced from whole beans were of a reasonable consistency but were not as mechanically strong as soybean flakes and tended to break up during handling. The decorticated beans had a low moisture content (1.1-2.3%) and did not flake, but rather formed a powder. Increasing the moisture content of the decorticated beans by live steam treatment during conditioning allowed a flake to be produced, though the quality of this flake was poorer than that for whole beans.

In the pilot plant, the residual winged bean meal was more difficult to desolventize than soybean meal and, to remove the last traces of solvent from the meal, it had to be heated above 100 C and subjected to a slight vacuum. However, it is concluded that a full-scale solvent extraction plant would have an oil extraction efficiency capable of producing a meal of less than 1% residual oil content (on a 10% moisture basis) from either whole or decorticated beans.

Economic considerations normally indicate that solvent extraction plants should be large. A plant of 300 tons/day capacity would cost just under US $2 million. In addition, costs of solvent and utilities sould have to be considered. The requirements for utilities of a plant to pretreat and solvent-extract based on the results recorded in Table I

TABLE V

Computed Oil Yields for Different Winged Bean Accessions

Residual oil content (%)	Oil extraction efficiency (%)	
	15% initial oil content	20% initial oil content
10	37	55.6
5	70.2	78.9
0.8 (solvent extraction)	95.4	96.8

would be:

Steam (dry and saturated at 150 psig)	430 kg/ton
Cooling water at 30 C	16 m^3/ton
Compressed air	18 scfm
Power	40 kWh/ton
Hexane	40 ton (1.5 ton/day loss)

The oil content of winged beans is low (15-20%) and, therefore, solvent extraction seems to be the best method for oil extraction in this case. However, of necessity, a solvent extraction plant must be large with a high daily throughput. The winged bean, though a traditional food crop in Southeast Asia, is not yet established as a commercial oilseed crop and the large quantities required for solvent extraction are not available at present. Until sufficient winged beans are available for processing in a solvent extraction plant, other oil extraction procedures must be considered.

Oil Expelling

Pilot scale expelling was investigated using the Hander "New Type 52" expeller which is similar to the Simon-Rosedowns Mini-40 press (Simon-Rosedowns Ltd., Hull, England). These expellers have a high speed of rotation for the worm (120 rpm) and are designed so that expensive ancillary facilities such as steam conditioning and rolling for oil cell rupture are not generally necessary. At steady state, they operate at a cage/barrel temperature of 90-110 C, depending on the oilseed.

Experiments showed that 70-80% of the oil in whole winged beans (16.1% oil, 7.8% moisture) could be extracted in a single pass through the expeller, producing oil cake flakes with an oil content of 3.3-5%. Throughput was 16.8 kg/hr. The crude oil, containing 5% foots, was filtered, producing an oil that was deep yellow in color with a strong beany smell.

Decreasing the barrel temperature to 70 C caused a marked decrease in oil extraction efficiency and the oil cake contained 8% oil. The foots content of the crude oil increased to 15%.

Computational studies (Table V) on winged beans of theoretical oil content of 15 or 20% to produce residual cakes containing 10% oil (average expeller performance) and 5% oil (good expeller performance) lead to the conclusion that average expeller performance would yield unacceptably low oil recovery on the lower oil accessions of winged beans. A well-maintained expeller operation typified by the above result might be acceptable but a detailed feasibility study would be required to arrive at any decision, taking into account the agronomic yield and possibilities for improving throughput. Also, the major revenue source would have to be the cake. Our findings for feed value of whole beans, micronized beans, cake and meal will be published elsewhere.

The crude oils have been refined and our results suggest that expelled oil has certain technical advantages over solvent-extracted oils.

Laboratory Refining

Expeller oil. No precipitate was observed in the degumming test, indicating the virtual absence of gums in the oil. The FFA content was low (0.05% as oleic acid), so alkali neutralization was unnecessary. The oil had a Lovibond color (10) of 10 red + yellow = 54 in a 1-in. cell, indicating that bleaching was necessary. The crude oil also had a strong beany smell.

As degumming and neutralization were unnecessary, the first postextraction process required was bleaching. Preliminary experiments showed no improvement in bleaching was obtained by increasing the bleach time from 1 min to 30 min. The results are recorded in Table VI. Commercial considerations indicate that an attractive yellow oil will have a 10R+Y value of around 20. Values above this were considered unacceptable and also values below 10 were judged to be unpleasantly pale. A value of below 4 indicated that, at 40 C, the oil was almost water-white. The results show that the oil bleached readily with Tonsil 60 (a highly activated bleaching earth) and also well with Tonsil Standard FF above 0.5%. The Fulmont 237 had to be used above 1% to achieve adequate bleaching. It should be noted that the Tonsil earths removed completely the beany smell of the expeller-produced oil.

Solvent-extracted oil from whole winged beans. Degumming tests showed a heavy precipitate of gums in the oil, which took 15 min to develop fully. Centrifugation produced a clear oil at 40 C with a loss of 2%. Degumming significantly improved the color of the oil, lowering the Lovibond value of 10R+Y from 74 to 59 (Table VI). The FFA content of the oil was 0.19%, so the oil was neutralized with 8° Baume sodium hydroxide. Some of the oil (0.45% by wt) was lost at this stage (not corrected for increase in moisture of the oil) and the FFA content was lowered to 0.08%. Neutralizing also improved the Lovibond color, reducing the 10R+Y value further from 59 to 52.8.

The results of bleaching are recorded in Table VI. Crude solvent-extracted oil bleached poorly with all bleaching earths at concentrations between 0.5 and 2.0%, indicating the strong interference of gums and FFA on the performance of bleaching earths. Degumming the oil effected a significant improvement in bleaching performance and, at concentrations of 1% or more, Tonsil 60 and Tonsil Standard FF bleached the degummed oil well. The FFA level in the crude oil (0.19%) was low, so although reducing this level to 0.08% effects a further improvement in bleachability of the oil, the improvement is not marked.

Solvent-extracted oil from decorticated winged beans. Degumming tests gave a heavy precipitate of gums in the oil which, upon centrifuging, yielded a clear oil at 40 C with a loss of 2%. Degumming significantly improved the color of the oil, lowering the Lovibond value from 62.7 to 50.4. The FFA content of the oil was 0.5%, so neutralization was effected with 8° Baume sodium hydroxide. The FFA level was lowered to 0.07% with a 1.4% (w/w) refining loss and the Lovibond color dropped from 50.4 to 45.1.

The results of bleaching are recorded in Table VI. The crude oil bleached poorly with each bleaching earth but bleaching was substantially improved by degumming the oil first. Lowering the FFA level from 0.5 to 0.07% effected further improvement in the bleachability of the oil.

Commercial Refining of Solvent-Extracted Oil from Whole Winged Beans

The crude oil used for this study had a high phosphorus

TABLE VI

Effect of Laboratory Degumming and Caustic Refining on Bleachability of Winged Bean Oil

	Bleaching earth		Lovibond color (10R+Y)		
	Type	%	A*	B	C
Crude oil		–	54.0	62.7	74.0
	Fulmont 237	0.5	45.0	63.3	69.0
		1.0	28.0	59.8	68.5
		2.0	12.5	44.0	62.0
	Tonsil Standard FF	0.5	28.0	60.7	68.8
		1.0	11.9	54.9	47.8
		2.0	6.7	47.7	32.0
	Tonsil 60	0.5	17.1	62.0	69.2
		1.0	3.6	59.8	52.6
		2.0	3.3	44.0	25.8
Degummed oil		–		50.4	59.0
	Fulmont 237	0.5		33.9	53.1
		1.0		32.7	43.8
		2.0		28.3	24.0
	Tonsil Standard FF	0.5		45.0	35.8
		1.0		23.4	26.1
		2.0		12.0	12.0
	Tonsil 60	0.5		37.1	13.0
		1.0		14.9	9.8
		2.0		10.5	7.0
Degummed neutralized oil		–		45.1	52.8
	Fulmont 237	0.5		27.6	40.0
		1.0		23.0	–
		2.0		8.3	21.7
	Tonsil Standard FF	0.5		17.0	42.0
		1.0		12.2	17.5
		2.0		9.0	10.5
	Tonsil 60	0.5		14.2	28.5
		1.0		11.1	–
		2.0		6.5	9.5

*A = expeller-produced oil from whole beans; B = solvent-extracted oil from whole beans; C = solvent-extracted oil from decorticated beans.

TABLE VII

Commercial Caustic and Physical Refining of Oil from Whole Winged Beans

		Caustic	Physical
Phosphorus (ppm)	Crude oil	270	
	Degummed oil	13	8
	Bleached oil	5	Negligible
Phosphatides (%)	Crude oil	0.7	
Free fatty acids (% oleic)	Crude oil	0.2	
	Bleached oil	0.08	0.23
	Deodorized oil	0.03	0.04
Lovibond color (10 red+yellow)	Crude oil (inch)	47.0	
	Bleached oil (5¼ inch)	31.0	28.0
	Deodorized oil (5¼ inch)	18.6	19.5

content of 270 ppm, equivalent to a phosphatide content of 0.7% and had an FFA content of 0.2%. The results for physical and caustic refining of this oil are recorded in Table VII.

Caustic refining of the oil presented no difficulties; the oil was readily degummed with a considerable lowering of the phosphorus level. Alkali neutralization lowered the FFA level which was further reduced during oil deodorization, and bleaching produced an acceptable final color. For physical refining, an initial oil degumming step was found to be necessary after which a high-quality oil was produced having good color, low acidity and no taste or smell.

Stability of Refined Oil from Whole Winged Beans

The AOM test was carried out on both caustic-refined and physically refined oil. Both oils had an AOM stability of 17 hr, the time taken for the oil to achieve a peroxide value of 70 meq/kg of oil. This AOM value is what might be expected from the known fatty acid composition of the oil, the major fatty acids being oleic and linoleic acids with a very low level (about 1%) of linolenic acid (4).

Solid/Liquid Ratio of Winged Bean Oil

The percentage of solid fat in the oil at temperatures be-

TABLE VIII

Percentage of Solid Fat in Winged Bean Oil as a Function of Temperature

Temperature (C)	Solid fat content by NMR (%)
5	27.0
10	22.3
15	12.5
20	3.6
25	2.3
30	1.9
35	0.4
40	0

tween 5 and 40 C is recorded in Table VIII. The solid fat content as a function of temperature for winged bean oil is unusual. Below 20 C, the solid content increases rapidly. Particularly troublesome is the small percentage of what appears to be high-melting-point glycerides which are solid between 20 and 35 C.

The solid/liquid ratio of winged bean oil might have important consequences regarding its application potential. At laboratory ambient temperature (around 20 C), the extracted oil had a cloudy appearance which was not esthetically attractive. Upon prolonged standing, a solid settled, leaving a bright clear oil. At 40 C, the oil was completely clear. The clouding of the oil appeared to be due to the presence of a small amount of high-melting triglyceride. If the oil were to be retailed in clear bottles for food use in the tropics, this haziness would have to be previously removed by filtration or centrifugation. At 5 C, 27% of the oil is solid which would have to be removed by winterization if a salad oil or liquid shortening usage were envisaged.

ACKNOWLEDGMENTS

J. M. Robinson measured mass spectra and J. H. Beaumont decorticated the winged beans. The work described in this paper was done as part of a contract funded by the European Commission in collaboration with the Thailand Institute of Scientific and Technological Research, who supplied the plant material.

REFERENCES

1. Berry, S.K., Malays. Appl. Biol. 6:33 (1977).
2. Garcia, V.V., J.K. Palmer and R.W. Young, JAOCS 56:931 (1979).
3. New Sci. 75:356 (1977).
4. Claydon, A., Plant Foods Man 2:203 (1979).
5. Khan, T.N., and G.E. Eagleton, Advances in Legume Science, edited by R.J. Summerfield and A.H. Bunting, MAFF Royal Botanic Gardens Kew., 1980, pp. 383-392.
6. The Winged Bean—A High Protein Crop for the Tropics, National Academy of Sciences, Washington, DC, 1975, p. 41.
7. British Standards Institute, London, 1968, Method BS 4289.
8. Use of the Newport Quantity Analyser as a Replacement for Solvent Extraction for Measuring the Oil and Fat Content of Oilseeds, Chocolate, Meat and Other Materials, Oxford Analytical Instruments, Oxford, 1969, p. 33.
9. Official and Tentative Methods of the American Oil Chemists' Society, AOCS, Chicago, IL, 1955, Method Ca 2d-25.
10. British Standards Institute, London, 1958, 1976, 1977, Method BS 684.
11. Davis, J.B., J.M. Robinson, N.K. Silva and A. Barranco, J. Food Technol. 14:253 (1979).
12. Newport Quatity Analyser as a Replacement of Dilatometry in the Measurement of the Solid/Liquid Ratio of Edible Fats, Oxford Analytical Instruments, Oxford, 1972, p. 33.
13. Official and Tentative Methods of the American Oil Chemists' Society, AOCS, Chicago, IL revised 1959, Method Cd 12-57.
14. Newell, C.A., and T. Hymowitz, New Agricultural Crops, edited by G.A. Ritchie, AAAS Selected Symposium 38, Westview Press, Colorado, pp. 21-40.
15. Cerny, K., M. Kordylas, F. Pospisis, O. Svabensky and B. Zajic, Br. J. Nutr. 29:293 (1971).
16. Rao, P.U., and B. Belavady, J. Plant Foods 3:169 (1979).

[Received May 12, 1981]