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Regional Variation in Shea Butter Lipid and Triterpene Composition in Four African Countries†

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The triacylglycerol, fatty acid, and polycyclic triterpene compositions of shea butter were determined for 150 samples from the sub-Saharan countries of Mali, Burkina Faso, Nigeria, and Uganda. The compositional profiles showed high variability in all three classes of compounds. Shea butter is made up mainly of four triglycerides (TAG) differing in carbon number (CN) by two, starting from CN 50 to CN 56. The greatest source of variation was in the CN 54 TAG. Shea butter is characterized by 16 saturated and unsaturated fatty acids in greatly varying proportion, the major ones being the even homologues in the range of $C_{16}-C_{20}$. Oleic acid is dominant in Ugandan provenances, whereas stearic acid is dominant in West African shea butter. Acetyl and cinnamyl polycyclic triterpene means for countries ranged from 3.69 to 12.57%, with the highest values found in Nigerian provenances. Statistical comparisons of fat composition show that the geographic distance between shea populations is reflected in the degree of separation of their chemical profiles.

KEYWORDS: ***Vitellaria paradoxa*; fat composition; triglycerides; acetyl and cinnamyl polycyclic triterpenes; chemometrics**

INTRODUCTION

The shea tree [family Sapotaceae, *Vitellaria paradoxa* C.F. Gaertner, synonym *Butyrospermum parkii* (G. Don) Hepper] is indigenous to the savanna belt extending across sub-Saharan Africa north of the equator (*1*, *2*). The most valued product is shea butter (Francophone usage: beurre de karité), the fat extracted from the kernels. Shea nuts have a long history as a commodity of trade (*3*). Processed shea butter is used primarily as a cocoa butter additive in chocolate manufacture, although it is increasingly popular in cosmetic product formulations. Within Africa, the nutritious shea fruit pulp is of dietary importance (*4*), whereas the bark and latex play a role in ethnomedicine (*5*).

Shea kernels and shea butter have been found to have high levels of phenolic compounds and tocopherols, with significant regional variation in the content of these antioxidants (*6*, *7*). We wished to explore and determine whether significant differences in seed fat qualitative and quantitative composition exist among widely dispersed *V. paradoxa* populations. We were particularly interested in whether natural variants synthesizing triglycerides characterized by a higher melting point or those with a higher polycyclic triterpene content could be found among the different *V. paradoxa* ecotypes or provenances. These traits are sought after by the chocolate and cosmetic industries (*8*−*11*).

The two most popular analytical techniques for the analysis of triglycerides consist of reverse phase high-pressure liquid chromatography (RP-HPLC) (*12*) and high-resolution gas chromatography (HRGC) (*11*, *13*). We applied the latter technique that improved the resolution of individual triglyceride species by carbon number and allowed also the detection, on the same chromatogram, of polycyclic triterpenes (sterols, 4-methylsterols, triterpene alcohols) esterified either with acetic or with cinnamic acid (*12*, *13*). Aiming to develop strategies to guide in the identification of shea nut populations with appropriate triterpenes and triacylglycerol composition for various food and nonfood industries, we carried out a qualitative and quantitative composition and statistical study based on over 150 samples of nuts of *V. paradoxa* provenances from the sub-Saharan countries of Mali, Nigeria, Burkina Faso, and Uganda.

EXPERIMENTAL PROCEDURES

Materials. Shea nuts were analyzed from nine locations in both Mali and Burkina Faso, two locations in Nigeria, and an aggregate regional collection from northern Uganda (see **Table 1**). Shea ecotypes in Uganda are considered to be *V. paradoxa* subspecies *nilotica*, whereas the rest of the samples from Mali, Burkina Faso, and Nigeria are from populations of *V. paradoxa* subspecies *paradoxa*.

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† This manuscript is dedicated to Prof. Giorgio Bianchi, Director of the Istituto Sperimentale per la Elaiotecnica, Città Sant'Angelo (PE), Italy, who passed away in October 2004.

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Table 1. Mean Fat Percentages of Shea Kernels from Mali, Burkina Faso, Nigeria, and Uganda

Mali			Burkina Faso			Nigeria			Uganda	
shea		fat content (%)	shea		fat content (%)	shea		fat content (%)		fat content (%)
Sirakorola	mean	41.17	Souly	mean	46.90	Kontagora	mean	48.53	mean	53.12
	SD ($n = 7$)	0.09		SD ($n = 8$)	0.08		SD ($n = 8$)	0.05	SD ($n = 22$)	0.05
Sebekoro	mean	42.80	Touroum	mean	47.58	Mokwa	mean	47.08		
	SD ($n = 7$)	0.04		SD ($n = 4$)	0.17		SD ($n = 9$)	0.04		
Gouani	mean	48.59	Yasso	mean	51.32					
	SD ($n = 7$)	0.07		SD ($n = 6$)	0.05					
Massala	mean	44.80	Sapone	mean	47.64	SD of mean		0.01		
	SD ($n = 7$)	0.06		SD ($n = 8$)	0.04	SD of all samples ($n = 17$)		0.04		
Niamana	mean	45.10	Peni	mean	55.18	mean of all samples ($n = 17$)		47.76		
	SD ($n = 7$)	0.06		SD ($n = 8$)	0.03					
Koumantou	mean	51.33	Lan	mean	48.08					
	SD ($n = 7$)	0.06		SD ($n = 5$)	0.05					
M'Peresso	mean	41.90	Tambissini	mean	46.22					
	SD ($n = 6$)	0.08		SD ($n = 9$)	0.06					
Badougou	mean	43.99	Siniena	mean	49.19					
	SD ($n = 7$)	0.13		SD ($n = 7$)	0.06					
Fourou	mean	48.10								
	SD ($n = 9$)	0.04	SD of mean		0.03					
			SD of all samples ($n = 55$)		0.07					
SD of mean		0.03	mean of all samples ($n = 55$)		49.03					
SD of all samples ($n = 64$)		0.07								
mean of all samples ($n = 64$)		45.41								

Fat Content. Nuts were oven-dried and decorticated, and the kernels were crushed in a mortar and ground in a coffee mill. Samples thus prepared were weighed and extracted with hexane at room temperature for 3 h, and the fat content was determined gravimetrically after removal of the solvent by rotary evaporation (*14*).

Fat Class Detection and Separation. A variety of analytical techniques were used to explore the general chemical composition of shea butter, including thin-layer chromatography (TLC) done with silica gel G 60 (Merck). Spots were visualized by UV−visible spectrophotometry (254 nm), elution of triterpene fractions via silica gel G 60 column, followed by GC (Carlo Erba 5160 Mega), GC-MS (HP5988A), and NMR (Bruker model AC 300 spectrometer, Bruker Instruments, Inc., Karlsruhe, Germany) for individual component identification. The polycyclic triterpene components were identified by comparison of GC retention times, MS fragmentation patterns, and ^{1}H NMR using $CDCl_3$ as solvent data reported in the literature (discussed elsewhere). This paper focuses on composition comparisons of regional provenances using HRGC.

Triacylglycerol (TAG) and Polycyclic Triterpene GC Profiles. TAGs and polycyclic triterpene derivatives of the oils (butter) were analyzed using HRGC (*12*, *13*, *15*, *16*). Samples (20 mg) were dissolved in 2 mL of isooctane, and 2 μL of this solution was subjected to HRGC. A Carlo Erba 5160 Mega series gas chromatograph was equipped with a fused-silica capillary column, Quadrex 007-65 HT-15-0.1F (15 m × 0.25 mm i.d., 0.1 μm), FID, and a split/splitless injector. The column oven temperature was programmed from 270 to 290 °C at the rate of 2 °C/min and from 290 to 345 °C at 8 °C/min, was held for18 min at 345 °C, was raised from 345 at 350 °C at 2.5 °C/min, and finally was held at 350 °C for 5 min when the last peak came out. Detector and injection ports were maintained at 360 and 320 °C, respectively. The inlet pressure of hydrogen as carrier gas was 50 kPa. Peaks were identified by comparison with standards and retention time.

Fatty Acid Analysis. Fatty acid methyl esters were prepared by using KOH methylation (*14*, *17*). A sample (0.25 g) of oil was dissolved in hexane (2.5 mL) and the flask shaken for 30 s to complete solution. Methanolic KOH (0.3 mL, 2 N) was added, and the flask, covered with a glass cork, was shaken vigorously for 60 s. The organic layer containing the fatty acid methyl esters was separated from the methanolic phase after centrifugation for 5 min at 3500 rpm.

The organic layer containing the fatty acid methyl esters was removed and used for GC analysis. A Carlo Erba HRGC 8560 Mega 2 series gas chromatograph was equipped with a Supelco-SP-2380 capillary column (60 m × 0.32 mm i.d., 0.20 μm film thickness) and with a FID (t = 250 °C). The conditions were as follows: oven temperature program, 1 min at 70 °C, raised from 70 to 165 °C at 22 °C/min, held for 10 min at 165 °C, raised from 165 to 200 °C at 5 °C/min, held for10 min at 200 °C, raised from 200 to 245 °C at 8 °C/min, and finally held at 245 °C for 15 min; the inlet pressure of the hydrogen as carrier gas was 50 kPa; injection by "on column".

Identification of fatty acids was done by the use of standards and was confirmed by GC-MS analysis. Percent fatty acid was obtained by dividing the peak area of the individual fatty acid by the sum of all peak areas obtained for fatty acids by using an integrator.

Statistical Analysis. Linear discriminant analysis (LDA) using SPSS software was used for direct comparisons between pairs of countries for all analyzed parameters (*18*). The objective was to identify the compositional factors characterizing or distinguishing each region as previously reported for Italian olive oil varieties (*19*, *20*). ANOVA mean separations for TAG, fatty acids, and triterpene values were peformed using Statistica software (*21*).

RESULTS AND DISCUSSION

Separation of Triglycerides and Polycyclic Triterpenes. **Figure 1** shows the HRGC profile used to separate triglyceride species by fatty acid composition (described and discussed elsewhere) and fractionation of the two groups of triterpenes found in shea butter. Detection of the triterpene fractions show of one group of acetyl-esterified polycyclic triterpenes rapidly eluted from the GC column close to the origin of the chromatogram and a second group of cinnamyl-esterified polycyclic triterpenes eluted in the middle of the chromatogram just before the triglyceride fraction. In agreement with previous studies (*12*, *22*−*25*), this HRGC profile reveals the presence of at least four major components in each of the triterpene fractions. Comparison of MS and ^{1}H NMR data of these two triterpene groups

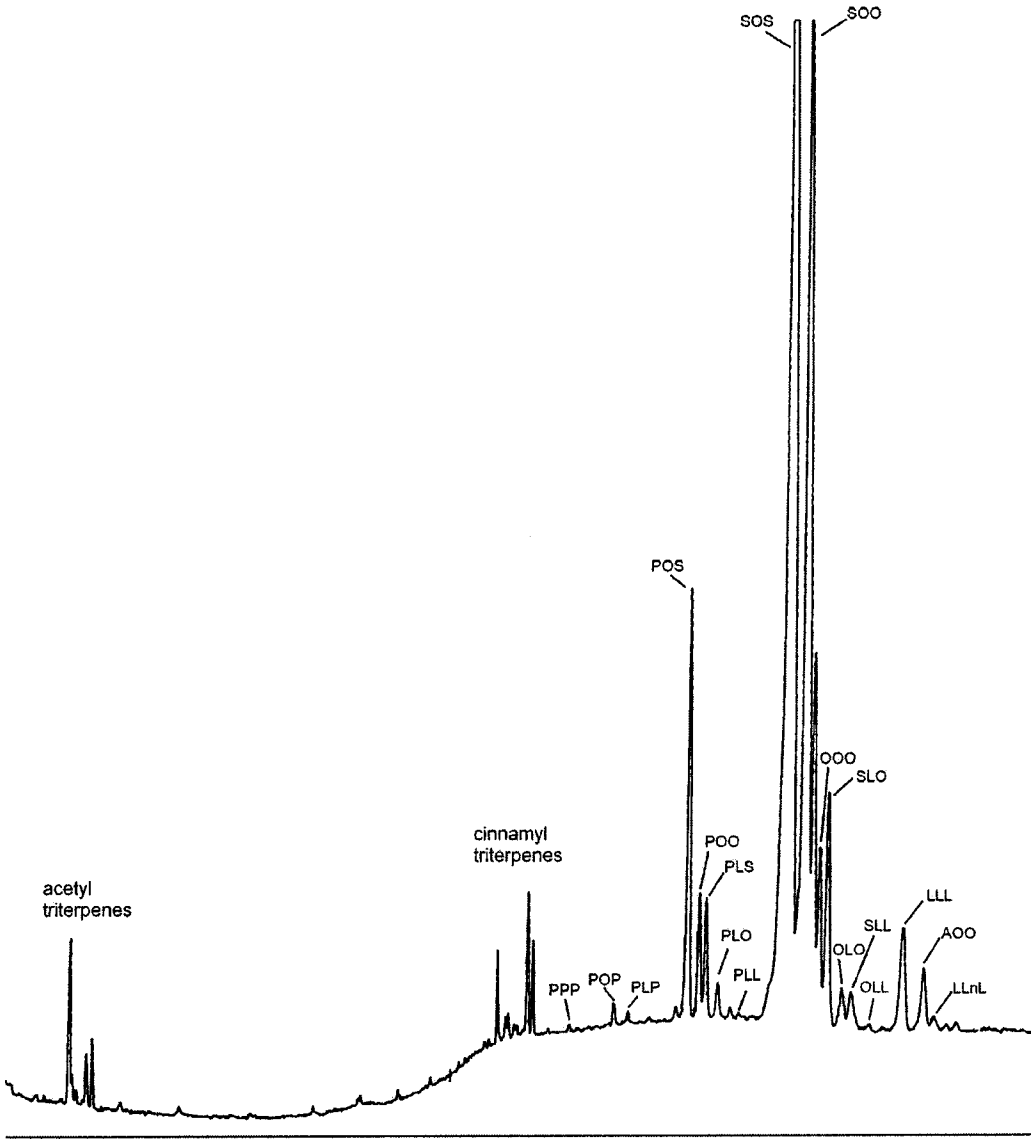


Figure 1. HRGC chromatogram showing triterpene and triglyceride peaks.

with those reported in the literature (*24*−*28*) confirmed the identification of the following trans triterpenol acetate and triterpenol cinnamate esterified polycyclic triterpene components: α-amyrin, *β*-amyrin, leupol, and butyrospermol, as shown in **Figure 2**. In agreement with our results, some other studies (*25*, *28*, *29*) dealing with various plant species reported on a mixture of fatty acids and cinnamic acid esters of triterpene alcohols.

Kernel Fat Content. Data in **Table 1** show higher kernel fat contents and less variation within and between sites than reported in a previous paper (*8*), likely due to differences in fat determination methodology. In the present study, site means ranged from 41 to 55%, with an overall mean of 48% (158 samples analyzed). Among countries, Uganda had the highest mean kernel fat content at 53%.

Fatty Acid Composition. Shea butter fat is characterized by 16 saturated and unsaturated fatty acids (**Table 2**), although in greatly different percentages: myristic (C14:0), pentadecanoic (C15:0), palmitic (C16:0), palmitoleic (C16:1), heptadecanoic (C17:0), stearic (C18:0), elaidic (C18:1, trans), oleic (C18:1, cis), a fatty acid accompanying oleic acid (C18:1, 11 cis), linoelaidinic (C18:2, cis, trans), linoleic (C18:2, cis, cis), arachidic (C20:0), linolenic (C18:3, cis, cis, cis), eicosenoic (C20:1n−9), behenic (C22:0), lignoceric (C24:0), and traces of caproic (C6:0), caprylic (C8:0), capric (C10:0), and cerotic (C26:0) acids. For discussion and statistical calculation, only those acids present in a sensibly consistent amount (≥0.01%) were retained and considered.

Striking variations in fatty acid composition according to regional *Vitellaria* populations are observed only when Uganda populations are compared with those of the other countries examined. Uganda populations produce a butter in which oleic acid is the major component, amounting to an average value of 57.76%. The butter of Mali, Burkina Faso, and Nigeria has a much lower concentration of oleic acid, ranging from 42.0 to 46.2%.

Palmitic acid, the precursor of stearic acid in the chain elongation process from C16:0 to C18:0 (*30*), is present in an average concentration of 4.16% in the Ugandan shea butter, compared to an average value of ∼3.30% for the butter samples of the other three countries. Most of the previous comments on concentrations of each single major fatty acid are confirmed by the derived percentage values of saturated fatty acid (SFA), unsaturated (USFA), monounsaturated (MUFA), and polyun-

Table 2. Fatty Acid Profiles of Shea Butter Provenances from Mali, Burkina Faso, Nigeria, and Uganda[a]

shea		myr 14:0	pen 15:0	pam 16:0	Δpam 16:1	ept 17:0	ste 18:0	ela 18:1	ole 18:1	vac 18:1	lnl 18:2	lin 18:2	ach 20:0	;nn 18:3	eic 20:1	ben 22:0	lib 24:0	SFA	USFA	MUFA	PUFA
										Mali											
Sirakorola	mean	0.03	0.01	3.44	0.04	0.10	40.84	0.02	46.29	0.73	0.05	6.60	1.32	0.14	0.21	0.10	0.08	45.92	54.08	47.29	6.79
	SD ($n = 7$)	0.01	0.00	0.63	0.01	0.05	3.40	0.01	2.34	0.21	0.01	0.84	0.17	0.02	0.09	0.05	0.02				
Sebekoro	mean	0.02	0.05	4.02	0.02	0.07	42.07	0.18	44.41	0.55	0.04	6.75	1.29	0.13	0.19	0.12	0.09	47.73	52.27	45.35	6.92
	SD ($n = 7$)	0.01	0.11	1.07	0.01	0.01	4.23	0.43	2.37	0.57	0.02	1.35	0.29	0.03	0.06	0.05	0.04				
Gouani	mean	0.01	0.00	3.20	0.02	0.07	42.82	0.01	45.71	0.69	0.04	5.80	1.17	0.11	0.19	0.10	0.06	47.43	52.57	46.62	5.95
	SD ($n = 7$)	0.01	0.00	0.25	0.01	0.00	2.66	0.01	2.18	0.14	0.03	0.64	0.09	0.02	0.04	0.04	0.01				
Massala	mean	0.02	0.00	3.57	0.03	0.07	43.83	0.02	43.46	0.61	0.05	6.46	1.35	0.12	0.26	0.09	0.06	48.99	51.01	44.38	6.63
	SD ($n = 7$)	0.00	0.00	0.47	0.01	0.00	4.49	0.00	3.71	0.19	0.01	0.63	0.13	0.03	0.06	0.01	0.01				
Niamana	mean	0.02	0.01	2.98	0.02	0.08	45.31	0.01	43.40	0.39	0.06	5.48	1.54	0.19	0.27	0.14	0.10	50.18	49.82	44.09	5.73
	SD ($n = 7$)	0.01	0.00	0.42	0.01	0.01	2.93	0.01	2.09	0.15	0.01	0.77	0.28	0.05	0.09	0.04	0.04				
Koumantou	mean	0.01	0.01	2.95	0.03	0.07	44.37	0.01	44.26	0.54	0.05	5.34	1.64	0.16	0.31	0.15	0.10	49.30	50.70	45.15	5.55
	SD ($n = 7$)	0.00	0.00	0.56	0.01	0.01	4.12	0.01	3.41	0.19	0.01	0.58	0.25	0.03	0.06	0.04	0.03				
M'Peresso	mean	0.02	0.01	3.08	0.02	0.07	43.32	0.01	44.90	0.38	0.05	5.98	1.45	0.19	0.29	0.14	0.09	48.18	51.82	45.60	6.22
	SD ($n = 6$)	0.00	0.00	0.28	0.01	0.02	2.52	0.00	1.90	0.15	0.01	0.91	0.11	0.03	0.04	0.01	0.02				
Badougou	mean	0.01	0.01	3.52	0.03	0.08	45.84	0.02	42.01	0.45	0.05	5.51	1.75	0.15	0.25	0.19	0.13	51.53	48.47	42.76	5.71
	SD ($n = 7$)	0.00	0.00	0.51	0.01	0.01	3.18	0.01	2.26	0.16	0.01	0.84	0.22	0.03	0.06	0.05	0.04				
Fourou	mean	0.01	0.01	3.28	0.02	0.07	41.81	0.01	46.18	0.36	0.05	5.88	1.58	0.19	0.32	0.14	0.09	46.99	53.01	46.89	6.12
	SD ($n = 9$)	0.00	0.01	0.74	0.01	0.01	4.07	0.01	3.16	0.14	0.01	0.93	0.21	0.03	0.05	0.02	0.02				
SD of mean			0.00	0.02	0.34	0.01	0.01	1.65	0.06	1.42	0.14	0.01	0.52	0.19	0.03	0.05	0.03	0.02			
SD of all samples ($n = 64$)					0.01	0.04	0.65	0.01	0.02	3.72	0.14	2.86	0.27	0.01	0.94	0.26	0.04	0.08	0.05	0.03	
										Burkina Faso											
Souly	mean	0.02	0.01	3.89	0.03	0.07	41.06	0.02	46.12	0.45	0.04	5.95	1.57	0.19	0.30	0.16	0.12	46.90	53.10	46.92	6.18
	SD ($n = 8$)	0.01	0.01	0.55	0.01	0.01	4.27	0.01	3.69	0.12	0.01	0.75	0.16	0.06	0.11	0.03	0.02				
Touroum	mean	0.01	0.01	3.04	0.02	0.07	43.67	0.01	44.63	0.29	0.05	5.48	1.87	0.17	0.37	0.18	0.13	48.98	51.02	45.32	5.70
	SD ($n = 4$)	0.00	0.00	0.33	0.01	0.01	4.55	0.01	3.93	0.15	0.01	0.36	0.16	0.03	0.06	0.01	0.02				
Yasso	mean	0.01	0.01	3.37	0.02	0.07	42.59	0.01	45.20	0.38	0.05	6.00	1.58	0.18	0.29	0.15	0.09	47.87	52.13	45.90	6.23
	SD ($n = 6$)	0.00	0.00	0.58	0.01	0.01	2.15	0.01	1.84	0.15	0.01	0.62	0.14	0.02	0.04	0.03	0.02				
Sapone	mean	0.01	0.01	2.98	0.03	0.07	45.84	0.02	42.62	0.30	0.05	5.79	1.59	0.17	0.29	0.14	0.09	50.73	49.27	43.26	6.01
	SD ($n = 8$)	0.00	0.00	0.16	0.04	0.01	3.88	0.01	3.98	0.13	0.01	0.84	0.15	0.03	0.04	0.01	0.01				
Peni	mean	0.01	0.01	3.03	0.03	0.07	42.61	0.01	45.86	0.50	0.05	5.65	1.47	0.19	0.31	0.12	0.08	47.40	52.60	46.71	5.89
	SD ($n = 8$)	0.00	0.00	0.67	0.01	0.01	3.21	0.00	2.84	0.21	0.01	1.14	0.09	0.03	0.06	0.01	0.01				
Lan	mean	0.01	0.01	3.59	0.02	0.08	43.49	0.01	44.64	0.34	0.05	5.77	1.36	0.17	0.25	0.12	0.09	48.75	51.25	45.26	5.99
	SD ($n = 6$)	0.00	0.00	0.69	0.01	0.01	3.83	0.00	3.56	0.09	0.01	0.67	0.18	0.03	0.06	0.02	0.02				
Tambissini	mean	0.02	0.01	3.06	0.02	0.07	45.18	0.01	43.11	0.33	0.05	5.87	1.59	0.17	0.27	0.14	0.10	50.17	49.83	43.74	6.09
	SD ($n = 8$)	0.03	0.01	0.28	0.01	0.01	2.00	0.01	2.41	0.05	0.01	1.08	0.14	0.04	0.03	0.02	0.03				
Siniena	mean	0.01	0.01	3.19	0.02	0.07	43.58	0.02	43.89	0.32	0.05	6.57	1.55	0.20	0.30	0.13	0.09	48.63	51.37	44.55	6.82
	SD ($n = 7$)	0.00	0.00	0.30	0.01	0.01	1.90	0.01	1.45	0.12	0.01	0.72	0.11	0.02	0.02	0.02	0.02				
SD of mean			0.00	0.00	0.33	0.01	0.00	1.51	0.01	1.24	0.08	0.00	0.32	0.14	0.01	0.03	0.02	0.02			
SD of all samples ($n = 55$)					0.01	0.01	0.55	0.02	0.01	3.43	0.01	3.12	0.14	0.01	0.84	0.17	0.04	0.06	0.03	0.03	
										Nigeria											
Kontagora	mean	0.02	0.01	3.37	0.03	0.08	44.24	0.02	44.09	0.38	0.04	5.55	1.50	0.20	0.23	0.15	0.11	49.48	50.52	44.75	5.79
	SD ($n = 8$)	0.00	0.00	0.27	0.01	0.01	3.15	0.01	3.06	0.14	0.01	0.61	0.17	0.04	0.04	0.02	0.02				
Mokwa	mean	0.02	0.01	3.34	0.03	0.07	43.40	0.02	44.56	0.42	0.05	6.03	1.41	0.18	0.24	0.13	0.09	48.47	51.53	45.27	6.26
	SD ($n = 9$)	0.00	0.00	0.43	0.01	0.01	2.75	0.01	2.52	0.18	0.01	0.26	0.13	0.02	0.03	0.02	0.02				
SD of mean			0.00	0.00	0.02	0.00	0.00	0.59	0.01	0.33	0.03	0.00	0.34	0.06	0.01	0.01	0.01	0.01			
SD of all samples ($n = 17$)					0.00	0.00	0.35	0.01	0.01	2.89	0.01	2.72	0.16	0.01	0.51	0.15	0.03	0.03	0.02	0.02	
										Uganda											
	mean	0.02	0.01	4.16	0.05	0.08	28.90	0.12	57.76	0.83	0.03	6.31	1.04	0.23	0.25	0.12	0.09	34.42	65.58	59.01	6.57
	SD ($n = 22$)	0.00	0.01	0.47	0.03	0.02	3.40	0.24	3.53	0.37	0.02	0.54	0.13	0.03	0.08	0.02	0.02				

[a] SFA, saturated FA (14:0, 15:0, 16:0, 17:0, 18:0, 20:0, 22:0, 24:0); USFA, unsaturated FA (16:1, 18:1, 18:2, 18:3, 20:1); MUFA, monounsaturated FA (16:1, 18:1, 20:1); PUFA, polyunsaturated FA (18:2 and 18:3). n = number of samples.

saturated (PUFA). In the case of polyunsaturated fatty acids, their percentages are slightly greater for some Ugandan shea provenances. These findings are in agreement with values reported in the literature for shea butter fatty acid composition (*8*, *11*, *31*).

Triglyceride Composition. A typical HRGC chromatogram of triglycerides of shea butter is shown in **Figure 1**. The chromatogram shows four major TAG groups of peaks that differ in carbon number (CN) by two, starting from CN 50 to CN 56. Lower carbon numbers such as CN 48 and carbon numbers higher than CN 56 were not considered because, being present in very low amounts, they gave very small peaks that were difficult to evaluate. Within each CN group the elution order was according to the unsaturation level: saturated were first eluted followed by mono-, di-, tri-, and polyunsaturated homologues, in that order. **Table 3** shows the mean triglyceride composition of the shea butter samples from the different locations examined. The major triglycerides of Uganda were SOO (33.39%), OOO (19.07), and SOS (19.87%), a quantitative composition quite different from those of Mali, Burkina Faso, and Nigerian shea butters, which together averaged 40% SOS, 26% SO), and 10% OOO. The concentration of saturated−unsaturated−saturated compared to saturated−unsaturated−unsaturated and unsaturated−unsaturated−unsaturated triglycerides determines the melting point of the butter, which is systematically lower for Ugandan butters (*3*, *8*).

No new triglycerides or fatty acids were detected, indicating that this collection of provenances does not contain biosynthetic

Table 3. Triglyceride (TAG) Composition of Shea Butter Provenances[a]

		TAG carbon number																			
		50		52				54								54	56	54			
shea		POP	PLP	POS	POO	PLS	PLO	15[b]	SOS	SOO	OOO	SLO	OLO	SLL	23[b]	LLL	AOO	LLnL	27[b]	28	29[b]
											Mali										
Sirakorola	mean	0.27	0.15	5.30	3.33	1.62	1.01	0.09	35.51	29.07	10.98	6.29	1.98	1.01	0.46	1.37	1.28	0.20	0.11	0.00	0.00
	SD ($n = 7$)	0.18	0.13	0.49	1.00	0.44	0.44	0.23	6.77	3.81	1.90	1.73	0.81	0.77	0.42	0.29	0.41	0.12	0.07	0.00	0.00
Sebekoro	mean	0.25	0.12	6.39	3.11	1.56	0.95	0.19	40.85	26.12	9.82	5.48	1.69	0.66	0.33	1.38	0.88	0.17	0.06	0.00	0.00
	SD ($n = 7$)	0.21	0.11	1.64	0.91	0.46	0.21	0.24	7.09	4.02	1.88	1.80	0.92	0.47	0.23	0.56	0.27	0.16	0.07	0.00	0.00
Gouani	mean	0.28	0.16	5.26	3.63	1.19	0.98	0.20	41.66	24.48	11.98	4.71	2.30	0.66	0.27	1.28	0.73	0.18	0.06	0.00	0.00
	SD ($n = 7$)	0.23	0.14	0.74	3.07	0.42	0.89	0.34	8.36	4.26	4.01	1.10	1.01	0.88	0.13	0.29	0.32	0.10	0.03	0.00	0.00
Massala	mean	0.14	0.06	5.86	3.83	1.70	1.00	0.14	41.82	23.74	10.80	4.88	1.46	0.59	0.22	1.85	1.49	0.30	0.11	0.01	0.00
	SD ($n = 7$)	0.07	0.04	0.85	1.94	0.20	0.37	0.29	7.91	5.25	3.03	0.95	0.74	0.27	0.14	0.32	1.15	0.18	0.10	0.02	0.01
Niamana	mean	0.13	0.08	5.43	2.65	1.35	0.78	0.15	45.78	24.76	9.72	4.34	1.24	0.29	0.14	1.81	1.09	0.16	0.06	0.00	0.00
	SD ($n = 7$)	0.11	0.07	0.83	1.27	0.25	0.25	0.28	3.33	2.97	2.56	0.66	0.66	0.25	0.08	0.35	0.22	0.12	0.05	0.01	0.00
Koumantou	mean	0.18	0.07	5.07	2.47	1.41	0.72	0.11	41.49	28.58	9.07	5.06	1.08	0.50	0.15	1.80	1.68	0.34	0.23	0.00	0.00
	SD ($n = 7$)	0.12	0.04	0.85	0.86	0.15	0.23	0.30	7.66	4.47	3.02	0.48	0.56	0.17	0.11	0.40	0.83	0.28	0.21	0.01	0.01
M'Peresso	mean	0.16	0.09	4.91	3.12	1.38	0.88	0.24	41.13	26.28	10.99	5.23	1.63	0.58	0.21	1.56	1.14	0.35	0.10	0.01	0.01
	SD ($n = 6$)	0.11	0.07	0.45	1.46	0.22	0.36	0.56	5.17	2.47	2.29	0.51	0.53	0.35	0.09	0.35	0.41	0.37	0.10	0.02	0.01
Badougou	mean	0.19	0.06	5.11	3.35	1.87	0.75	0.15	42.34	25.29	9.67	5.70	1.27	0.90	0.17	1.74	1.10	0.24	0.10	0.00	0.00
	SD($n = 7$)	0.25	0.06	2.32	2.25	0.48	0.22	0.26	5.74	3.20	2.14	1.82	0.64	1.00	0.11	0.28	0.43	0.18	0.08	0.00	0.01
Fourou	mean	0.13	0.07	4.48	3.25	1.37	0.86	0.14	38.90	28.33	11.47	5.49	1.72	0.56	0.25	1.57	1.16	0.16	0.08	0.00	0.00
	SD ($n = 9$)	0.11	0.07	1.92	2.13	0.55	0.48	0.25	6.84	3.33	2.88	1.55	1.47	0.47	0.20	0.37	0.40	0.13	0.07	0.01	0.13
SD of mean		0.06	0.04	0.55	0.43	0.21	0.11	0.05	2.75	1.95	0.97	0.58	0.38	0.21	0.10	0.21	0.29	0.08	0.05	0.00	0.00
SD of all samples ($n = 64$)		0.17	0.09	1.22	1.65	0.37	0.39	0.26	7.36	3.62	2.75	1.11	0.75	0.53	0.19	0.41	0.62	0.19	0.11	0.01	0.01
											Burkina Faso										
Souly	mean	0.13	0.07	6.14	3.20	1.54	0.92	0.08	39.05	27.58	10.28	4.92	1.63	0.56	0.25	1.81	1.44	0.29	0.13	0.00	0.00
	SD ($n = 8$)	0.06	0.04	1.20	0.73	0.25	0.30	0.24	6.79	3.14	3.33	0.70	1.03	0.34	0.21	0.15	0.45	0.20	0.12	0.00	0.00
Touroum	mean	0.12	0.05	5.03	2.57	1.46	0.86	0.10	38.79	27.90	10.77	5.78	1.61	0.61	0.31	1.91	1.46	0.62	0.07	0.00	0.00
	SD($n = 4$)	0.11	0.05	0.47	0.70	0.12	0.38	0.21	6.73	3.67	1.25	1.51	0.71	0.12	0.15	0.29	0.26	0.58	0.04	0.00	0.00
Yasso	mean	0.18	0.10	4.73	3.03	1.65	1.16	0.14	40.57	27.03	10.57	5.02	1.57	0.62	0.47	1.64	1.17	0.23	0.12	0.00	0.00
	SD ($n = 6$)	0.13	0.07	2.00	0.85	0.43	0.88	0.34	4.32	2.82	2.54	0.89	0.63	0.33	0.57	0.31	0.29	0.19	0.13	0.01	0.00
Sapone	mean	0.20	0.09	5.81	2.27	1.69	0.70	0.15	44.89	23.90	9.56	5.38	0.93	0.56	0.22	2.29	1.06	0.22	0.09	0.01	0.00
	SD ($n = 8$)	0.14	0.06	2.47	0.80	0.64	0.27	0.35	6.52	6.99	2.74	1.60	0.75	0.19	0.14	1.21	0.34	0.14	0.05	0.02	0.01
Peni	mean	0.12	0.05	5.00	2.94	1.36	0.79	0.05	39.85	29.32	10.62	4.75	1.28	0.56	0.22	1.54	1.28	0.20	0.07	0.00	0.00
	SD ($n = 8$)	0.05	0.03	1.24	0.96	0.43	0.37	0.13	8.62	5.27	1.70	1.26	0.69	0.48	0.20	0.37	0.39	0.19	0.04	0.00	0.00
Lan	mean	0.15	0.07	5.29	2.66	1.72	0.76	0.21	43.82	26.42	8.64	4.89	0.99	0.63	0.15	1.84	1.24	0.41	0.13	0.00	0.00
	SD ($n = 6$)	0.13	0.06	2.60	0.65	0.24	0.32	0.40	6.64	4.01	2.28	0.80	0.65	0.63	0.09	0.33	0.53	0.46	0.21	0.00	0.00
Tambissini	mean	0.20	0.10	5.54	2.81	1.59	0.82	0.13	42.67	26.02	10.32	4.99	1.23	0.39	0.15	1.75	1.03	0.18	0.07	0.00	0.00
	SD ($n = 8$)	0.10	0.06	0.86	0.54	0.35	0.20	0.35	3.79	1.51	2.10	1.20	0.57	0.32	0.06	0.36	0.23	0.11	0.04	0.00	0.00
Siniena	mean	0.12	0.11	4.94	3.06	1.55	0.80	0.11	41.31	26.41	10.59	5.54	1.22	0.64	0.24	1.75	1.19	0.35	0.09	0.01	0.00
	SD ($n = 7$)	0.04	0.06	0.56	1.47	0.22	0.25	0.00	1.02	2.60	1.37	0.60	0.29	0.29	0.13	0.11	0.19	0.22	0.03	0.02	0.00
SD of mean		0.04	0.04	0.02	0.48	0.30	0.12	0.14	0.05	2.24	1.58	0.72	0.36	0.27	0.08	0.10	0.22	0.16	0.15	0.03	0.00
SD of all samples ($n = 55$)		0.10	0.10	0.05	1.60	0.88	0.38	0.40	0.29	5.99	4.24	2.35	1.16	0.70	0.35	0.24	0.55	0.36	0.28	0.10	0.01
											Nigeria										
Kontagora	mean	0.23	0.06	5.70	2.52	1.13	0.62	0.26	44.59	26.02	9.19	4.92	1.17	0.45	0.17	1.71	0.99	0.20	0.06	0.01	0.00
	SD ($n = 8$)	0.35	0.07	0.66	0.62	0.37	0.18	0.51	5.38	4.12	2.68	1.34	0.61	0.32	0.14	0.07	0.35	0.18	0.05	0.02	0.01
Mokwa	mean	0.30	0.16	5.69	3.06	1.25	0.88	0.22	42.97	24.18	11.12	4.55	1.81	0.39	0.26	1.74	1.09	0.22	0.06	0.02	0.01
	($n = 9$)	0.19	0.12	0.63	0.71	0.13	0.15	0.48	5.07	2.25	2.76	0.27	0.58	0.17	0.07	0.24	0.38	0.13	0.04	0.03	0.01
SD of mean		0.05	0.08	0.01	0.38	0.09	0.18	0.03	1.15	1.30	1.37	0.26	0.45	0.04	0.07	0.02	0.07	0.01	0.00	0.01	0.00
SD of all samples ($n = 17$)		0.28	0.11	0.62	0.70	0.28	0.21	0.48	5.115	3.34	2.812	0.953	0.661	0.25	0.12	0.17	0.355	0.149	0.042	0.025	0.009
											Uganda										
	mean	0.00	0.00	4.49	5.50	1.31	1.19	0.37	19.87	33.39	19.07	6.70	4.30	1.08	0.80	0.91	1.02	0.00	0.00	0.00	0.00
	SD($n = 22$)	0.00	0.00	0.93	1.22	0.22	0.26	0.31	4.63	3.56	4.62	1.16	1.94	0.73	0.83	0.31	0.38	0.00	0.00	0.00	0.00

[a] TAG names indicate positional location of fatty acid in TAG; for abbreviations P, O, L, S, Ln, amd A, see text. n = number of sample. [b] Triglyceride molecular species not identified.

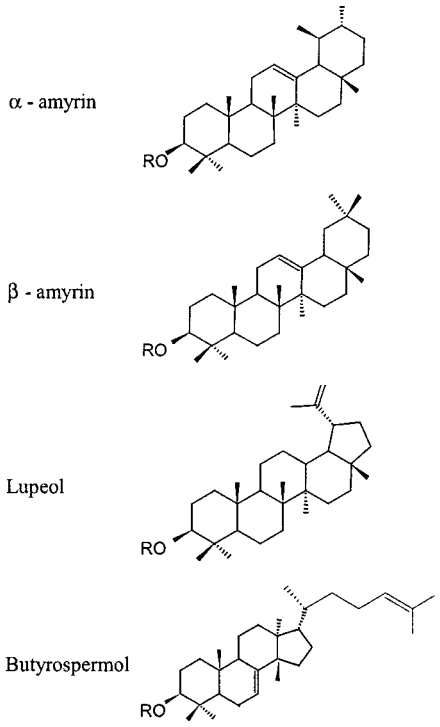
Table 4. Comparison of Acetyl and Cinnamyl Triterpene Means of Four African Countries[a]

country	acetyl triterpenes (%)	$\alpha = 0.05$	cinnamyltriterpenes (%)	$\alpha = 0.05$
Uganda	1.68	a	2.17	a
Burkina	3.20	b	4.47	b
Mali	3.88	b	6.33	c
Nigeria	5.79	c	7.68	d

[a] Significant differences at $\alpha = 0.05$ (Fisher's LSD) are noted.

enzymes with novel substrate specificities for the parameters investigated. According to the data presented, which fit well with the literature (*3*, *8*, *32*), the Ugandan provenances differ greatly from West African samples in the content of C16 and C18 saturated fatty acids. In this data set, comparison of shea butter provenances within a given country shows low variability in percentages of component fatty acids. In contrast, there is greater variation in TAG species, including the SOS triglyceride sought after by the chocolate industry (*8*).

Polycyclic Triterpene Content. Analysis of the percentages of acetyl and cinnamyl triterpene esters showed strong regional affinity. Country means ranged from 3.69 to 12.57%, with the highest values found in Nigerian provenances and lower values found in Ugandan butters (**Figure 3**). The triterpene content of



R = H, free triterpenol
R = CH_3CO, triterpenol acetate
R = $C_6H_5CH = CH - CO$, triterpenol cinnamate

Figure 2. Formulas of major polycyclic triterpenes of shea butter.

shea butter from Mali averaged 9.59%, whereas provenances from Burkina Faso averaged 7.09%. Triterpene mean separations were statistically significant at $\alpha = 0.05$, according to Fisher's LSD test. Statistically significant differences were stronger for cinnamyl triterpene content than for acetyl triterpenes (**Table 4**).

Integration of these data suggests that West African provenances had significantly higher levels of both acetyl and cinnamyl triterpenes than provenances of East Africa. These data should be of significant interest to the cosmetic and pharmaceutical industries (*6*, *7*, *33*).

Statistical Analysis. The chemometric statistical trends of the data reported here reflect the geographic separation among the *Vitellaria* populations examined. The LDA model recently demonstrated for accurate groups of olive oil classification (*19*, *20*) was applied to classify samples in clusters according to the country and to identify the variables that are significant for distinguishing among the countries. Statistical comparisons of provenances by country using LDA shows that Ugandan shea butter is compositionally distinct from the West African types, with close to 100% of the samples clearly different from the others (**Table 5**). Mali and Burkina Faso provenances are closest and could be separated correctly in only 64% of the cases. Nigerian shea butter provenances could be separated from the other two West African countries with a higher level of confidence. A similar geographic pattern was reported for a study using RAPD markers to assess gene flow and regional variation across the *Vitellaria* species range (*34*).

The overall results of this study show that the chemical constituents of shea butter are consistent across the species range, while at the same time the relative proportions of the constituents greatly vary. Regional variants exist with high concentrations of desired classes of compounds such as triterpenes. The data complement previous findings showing high

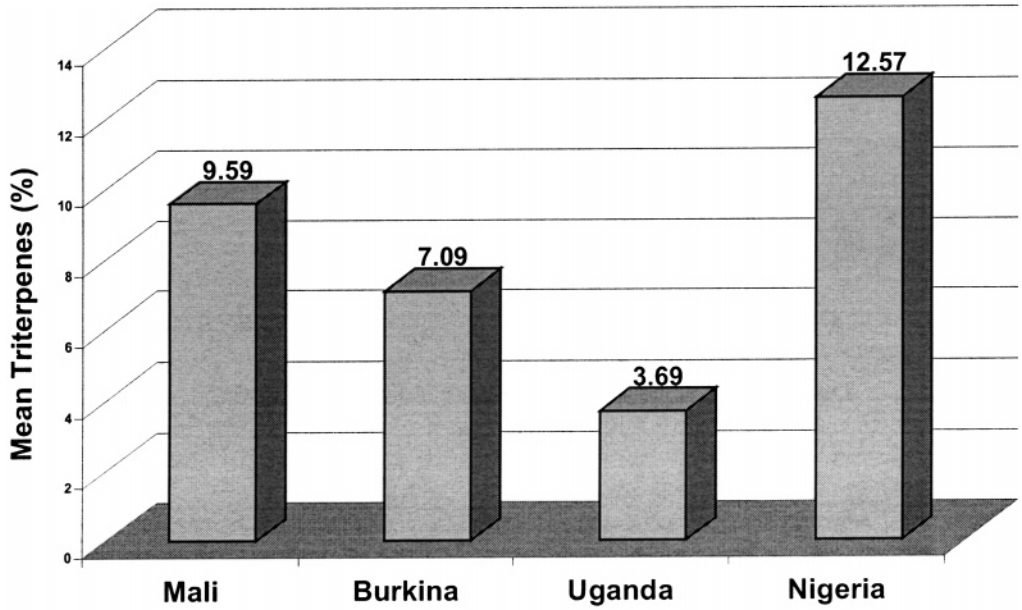


Figure 3. Comparison of total triterpene fractions. Values represent the mean of all provenances analyzed for each country.

Table 5. Comparison of Shea Butter Composition by Country Using Linear Discriminant Analysis (LDA)

paired comparisons		percentage of correct classification		
country 1	country 2	original case	cross-validation	selected variables
Mali	Burkina Faso	64.7	62.2	cinnamyl 8, linolenic acid
Mali	Nigeria	79.0	74.1	POS, PLS, linolenic acid
Nigeria	Burkina Faso	88.9	81.9	cinnamyl 8, PLS, LLL, eptadecanoi acid
Mali	Uganda	100	98.8	oleic acid, cinnamyl 10, eicosenoic and linolenic acids, PLS, SOS
Burkina Faso	Uganda	100	98.7	stearic and eicosenoic acids, cinnamyl 10, acetyl 5, acetyl 7, PLO, SOS
Nigeria	Uganda	97.4	100	SOS, stearic acid, OOO, arachic acid, SLL

endemic levels of catechins and tocopherols in some provenances or ecotypes, together with regionally characteristic triglyceride profiles (*6*−*8*).

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