End Use Quality of Some African Corn Kernels. 1. Physicochemical Characteristics of Kernels and Their Relationship with the Quality of "Lifin", a Traditional Whole Dry-Milled Maize Flour from Benin

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The physicochemical characteristics of eight samples of lifin, a traditional maize market flour of Benin, were determined. They had very similar proximate composition and a median particle size (PS*m*) under 200 μm; four, having a PS*m* under 180 μm, can be considered as fine or very fine and should be preferred by consumers. The grains of twenty-one maize cultivars of Benin including local ecotypes (5) and new cultivars (16) were physicochemically characterized and were tested for their ability to give fine whole grain flours. The five local ecotypes presented common traits such as high friability, low vitreousness, and dent kernel percentage giving relatively fine flours with low damaged starch content. On the contrary, most new cultivars had vitreous and hard grains and half gave very coarse flours with PS*m* over 200 μm. The more friable the grain was, the finer the whole grain flour it gave and the lower damaged starch it contained.

Keywords: *Maize; grain; hardness; physicochemical characteristics; milling; flour*

INTRODUCTION

Although maize (*Zea mays* L.) is not indigenous to Africa, having originated in South America, it has been nevertheless widely accepted by African culture and economy and has become the dominant cereal crop of the continent with an annual production of 30 million tons, before sorghum (15 million tons), wheat (13 million tons), and rice (10 million tons) (FAO, 1991; Cownie, 1993). The reasons for maize's dominant position are related to its suitability for the growing conditions and to its strategic role as a commercial crop and primary staple food in many African countries (Nago, 1989; Cownie, 1993).

In these countries, maize is mainly used for human consumption in various and numerous traditional forms including porridges, pastes, dumplings, cakes, fritters, and beverages (Table 1). In this respect, Benin is an interesting example with a high maize consumption level (more than 80 kg per inhabitant and per year) and a large diversity of derivative food products (Nago, 1989; CIMMYT, 1991). Among these African traditional products, two unfermented ones seem to be the most common and popular: the porridge that is widely used as weaning food and breakfast meal, and the thick paste (Table 1). These products are produced both for direct household consumption and for street vending by cooking in water the whole maize grain flour (like for the preparation of sorghum tô; Fliedel, 1994) differently named in the African countries concerned (lifin in Benin, Togo, and Nigeria). This traditional flour (representing more than 50% of maize utilization in Benin), was formerly obtained through two different traditional dry-milling systems (stone and pestle-and-mortar mills), but is nowadays prepared by three to five successive passes of whole cleaned dry grains through attrition disc mills, which have been introduced and distributed in many African countries over the last 40 years (Muller, 1970; Nago, 1989). Due to time constraints for urban households, this traditional whole grain flour is becoming an important ready-to-cook product in street businesses in many African countries (Nago, 1992).

A brief investigation (sample of 60 inhabitants) of two regions in the south of Benin (one rural zone with high maize production, one urban area with high maize product consumption level) showed that consumers prefer maize flour with white color and fine particle size, giving an elastic thick paste. Almost 90% of maize producers and millers questioned consider that new cultivars are too hard to be transformed in a good lifin; indeed, grinding hard grains is more difficult, more power-consuming, and more expensive (Agossou et al., 1986; Koudokpon, 1991; Tchamo, 1993). Grain quality, in terms of technological, organoleptic, and nutritional properties, has been generally neglected in local breeding programs that have been carried out mainly to develop high agronomic performance cultivars (with high field yield and resistance to drought and to pests, Table 2). Thus, new cultivars present generally inadequate grain characteristics and are not adopted by local farmers, traders, processors, and consumers (Kydd, 1989; Koudokpon, 1991): in Benin, only 10% of the production area of maize is planted with new cultivars (Anonymous, 1992). Therefore, there is a great need to adapt maize cultivars to their end uses and to breed new cultivars not only for their agronomic performance, but also for technological properties which provide for instance, local flour (lifin), porridge (koko), and paste (owo) with required organoleptic and rheological attributes (Stroshine et al., 1986; Peplinski et al., 1989; Mestres et al., 1991, 1995). Such approaches are beginning to emerge in African countries, but the lack of reference data about properties of these traditional African maize products (flour, porridge, and paste) and their relationships with maize grain characteristics represents a constraint in carrying out these new

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Table 1. Main Traditional Maize Products Used in Africa and Their Socioeconomical Significance[a]

product no.	product type: characteristics	countries where used (local name)	importance in human consumption	importance in food trading
1	*flour*: unfermented dry-milled from whole grain	Benin, Togo (lifin); Nigeria, Ghana, Zambia, Mali	very high	high
2	*unfermented porridge*: light ungranulated, water cooked from whole grain flour (product 1)	Benin, Togo, Ghana (koko); Nigeria; Cape Verde (papa)	very high	low
3	*unfermented thick paste*: consistent, firm, elastic, water-cooked from whole grain flour (product 1)	Benin (owo), Togo (akumé); Nigeria (ôka); Ghana (Banku); Burkina Faso (bêrê tô); Mali (kabaseri tô); Niger (kolkotihaou); Tchad (mour); Zambia (nshima); Kenya (ugali)	very high	high
4	*seasoned paste*: consistent, cooked from whole grain flour (product 1) mixed with oil and chicken "juice"	Benin, Togo (amiwo); Ghana	low	low
5	*slurry*: fermented, derivated from soaked dehulled and wet-milled grains	Benin, Togo, Ghana, Nigeria (ogi); Congo (poto poto)	very high	low
6	*dough*: fermented, derivated from dehulled and wet-milled grains	Benin, Togo (mawè); Ghana (mbor); Nigeria	high	high
7	*fermented porridge*: ungranulated, water-cooked from product 5 or 6	Benin, Togo, Ghana (koko); Nigeria (ogi porridge); Kenya	very high	low
8	*fermented and granulated porridge*: water-cooked from product 6	Benin, Togo (aklui); Mali (kabanênê)	high	high
9	*fermented thick paste*: consistent, elastic, water-cooked from product 5 or 6	Benin (akassa, lio); Togo (kafa, makumé); Nigeria (agidi, eko); Ghana (kenkey); Kenya (uji)	high	very high
10	*steam-cooked fermented paste*: cooked as balls from dough (product 6) mixed with wheat flour	Benin, Togo, Nigeria, Côte d'Ivoire, Cameroun, Congo, Ghana (ablô)	high	very high
11	*couscous*: granulated steam-cooked from dough (product 6) or hydrated flour (product 1)	Benin, Togo (yéké-yéké); Cape Verde (couscous); Senegal	low	low
12	*fritters*: derived from dough (product 6) or hydrated flour 1), fried in various oils after shaping in ball, slice, or ring forms	Benin, Togo, Ghana (kléklé, klaklu, ganvi, atshomo); Cape Verde (pastel)	high	high
13	*beverage* (local beer): fermented, cooked, processed from malted grains	Benin, Togo, Ghana, Nigeria, Niger (chakpalo, aliha)	high	high

[a] Sources: Müller (1970), Sautier et al. (1989), and Nago (1992).

approach programs successfully. Moreover in the literature, most reports on milling studies in African countries deal with the wet-milling processes (Akinrele, 1970; Olatunji, 1977; Umoh and Fields, 1981; Akobundu and Hoskins, 1982; Adeyemi et al., 1987; Sefa-Dedeh, 1989).

A few workers studied dry-milling behavior of maize, but in the production of traditional fermented African products (Umoh and Fields, 1981; Osungbaro, 1990). Many other authors reported on kernel physicochemical characteristics and dry-milling behavior of maize grains; but in most cases, processes have been performed for producing degerminated semolinas and cornmeal (Feillet and Redon, 1975; Paulsen and Hill, 1985; Pomeranz and Czuchajowska, 1987; Peplinski et al., 1989; Mestres et al., 1991, 1995). Endosperm texture (vitreousness) is commonly associated with hardness and dry-milling behavior of maize grains (Paulsen and Hill, 1985; Abdelrahman and Hoseney, 1984), but the friability index was found to be the best descriptor of maize milling ability and therefore a good breeding indicator for grain quality (Mestres et al., 1995). Other physical (kernel weight, test weight, and kernel shape factors, i.e., dent kernel percentage or sphericity) and chemical (ash and protein contents) grain characteristics are also currently used to determine maize kernel quality, but none can be considered as a precise indicator of maize dry-milling performance (Mestres et al., 1991, 1995; Dorsey-Redding et al., 1991).

Nevertheless, these results cannot be extrapolated to the African traditional dry-milling process and resulting products. As a first contribution in this field, we attempted first to characterize the African traditional whole grain flours by analyzing market samples and then to point out the grain attributes (physicochemical characteristics) of various African maize cultivars in close relationship with flour quality. Determining and understanding these relationships should help to better orient maize breeding programs according to African consumer's quality requirements and to predict corn grain dry-milling ability.

MATERIALS AND METHODS

Traditional Market Flours. Eight samples of dry-milled whole maize grain flours were purchased from different markets in the area of Cotonou (Benin) for determining reference data on the physicochemical properties of traditional products usually processed for human consumption in the country. Market flour samples were stored at room temperature for 4−6 months before analysis.

Maizes. Among the 12 local maize ecotypes mainly used in Benin, four were selected according to their importance; another was chosen because it has yellow grains (Table 2). In addition among a score of new cultivars being in use or extended in the country, 16 were selected to represent effectively the largest range of maize new cultivars (in terms of agronomic characteristics or physical and technological properties, Table 2). All grain samples (5−20 kg) were collected in Benin from Agronomic Research Institutes (Center for Research on Food crops in Niaouli, Applied Research in Rural Environment Program in Lokossa, and International Institute for Tropical Agriculture Center of Benin, in Agonkanmey) or Rural Extension and Production State Organisms (Lokossa, Abomey-Calavi, Porto-Novo). They were cultivated during the main growing season (March−July 1993), on ferrallitic soils in Southern region of Benin where the mean daily temperature and total rainfall registered were 26 °C and 975 mm, respectively. They received chemical fertilizers (100 kg/ha of NPK 14/23/14) 1 month after sowing, and the field was weeded two or three times during the growing period.

The samples were air-dried at ambient temperature (25−35 °C) to have less than 15% water content (wet basis) and stored at 4 °C. They were brought up to ambient temperature 1 day before analyses were performed.

Chemical Analyses. Moisture, ash, and free lipid contents were determined by oven-drying for 2 h at 130 °C, incineration

Table 2. Characteristics of Some Maize Cultivars in Use or Being Extended in Benin[a]

					average yield (tons/ha)				resistance against pests		resistance against diseases			
cultivar	type	origin	growing season[b]	duration of growing cycle (days)	in research center	at small farmer level	ear covering by shucks	resistance against drought	stalk borer	weavil	mildew	streak	kernel color	kernel preservation ability
Gbaévé	local ecotype	Benin	1 and 2	70		0.7	very good	good	good	fair		good	yellow	good
Gbogboué	local ecotype	Benin	1 and 2	90		0.8	very good	good	good	fair		fair	white	good
Gnonli	local ecotype	Benin	1 and 2	90		0.8	very good	good	good	fair			white	low
Gougba	local ecotype	Benin	1 and 2	90		0.8	very good	good		fair		fair	white	good
Djakpé	local ecotype	Benin	1 and 2	90			very good						white	good
DMR-ESR-W	composite	IITA[c]	1 and 2	90−95	4.5	2.0	fair	fairly good	very good	fair	fair	good	white	good
Poza Rica 7843-SR	composite	CIMMYT[d]	1	120	5.5	2.6	fair	fair	good	middling	fair	good	white	fair
Pirsabak7930 SR	composite	CIMMYT	1 and 2	90−100	4.0	2.5	good	low	good	fair	fair	good	white	good
Sékou 85	composite	SRCV-N[e]	1	120	4.5	2.5	fairly good	fair	good	good	fair	good	white	
B.M.L.	composite	SRCV-N	1 and 2	90	4.5		good	fair	fair	good	good	fair	white	fair
DMR-ESR-W × 28 Synthetic 1	composite	SRCV-N	1	110−120	3.5		fairly good	fair					white	
Gbogboué × TZSR-W	composite	IITA	1	120	5.0	2.8	good	fair	good	good	fair	good	white	
AB 11	composite	DNRA[f]	1 and 2	90		1.5	good	good	good	fair	good	good	white	
AB 12	composite	DNRA	1	120		2.0	good	good	good	good	good	good	white	
AB 13	composite	DNRA	1	120		1.6	good	good	good	good	good	good	white	
NH2-SR	intervarietal hybrid	SRCV-N	1 and 2	105	4.0	1.5	very good	fair	good	good	good	good	white	fair
TZSR-W	composite	IITA	1	100−110	4.0	2.3	good	low	good	good	good	good	white	
TZB-SE-SR	composite	IITA	1	120	5.5	2.3	low	low	good	low			white	low
TZPB-SR	composite	IITA	1	120	5.5	2.3	good	good	good	low	good	good	white	good
Sékou 85 × TZSR-W	composite	SRCV-N	1	120	5.0	2.5	good	fair	good	fair	good	good	white	
La Posta	composite	CIMMYT	1	120	4.5	2.0	fair	low	good	good	good	good	white	

[a] Sources : Koudokpon (1991), Vodouhé and Yallou (1993), and Dokoui (1993). [b] 1 = first growing season (April−July), 2 = second growing season (September−December). [c] International Institute for Tropical Agriculture, Ibadan, Nigeria. [d] Centro Internacional de Mejoramiento de Maize y Trigo, Mexico. [e] Section de Recherches sur les Cultures Vivrières de Niaouli, Benin. [f] Direction Nationale de la Recherche Agronomique, Togo.

Table 3. Physicochemical Characteristics of Eight Cotonou Market Maize Flours

flour number	water content (% wb)	crude protein (N × 6.25) (% db)	free lipids (% db)	fat acidity (mg KOH/100 g of dry matter)	damaged starch (% starch basis)	particle size index[a] at different sieve openings (μm) 125	150	180	212	250	315	median particle size (μm)
1	11.7	10.2	4.4	340	24.5	60.0	67.2	71.8	78.0	84.5	92.0	<125
2	12.1	10.7	4.7	330	28.5	39.5	47.5	55.5	64.8	74.9	85.8	160
3	11.5	10.2	4.4	370	23.4	38.0	48.0	55.2	63.6	71.7	82.2	160
4	11.4	11.1	4.6	430	24.2	28.9	37.4	44.2	53.1	62.0	74.6	200
5	11.2	10.0	4.6	300	28.0	32.3	40.6	49.9	57.6	67.7	82.5	180
6	12.2	9.8	4.4	390	28.2	38.5	48.0	55.4	65.0	74.8	86.0	160
7	11.3	10.4	4.4	350	28.9	44.0	52.1	59.5	68.3	76.5	86.3	140
8	11.7	10.1	4.6	320	36.0	33.5	40.8	47.9	57.3	67.1	79.7	190
mean value	11.6	10.3	4.5	350	28	40	48	55	63	72	84	
cvs (%)[b]	3	4	3	11	14	24	18	14	11	9	6	

[a] Cumulative percentage of particles passing through the sieve. [b] Coefficient of variation between samples.

for 2 h 30 min at 900 °C, and diethyl ether extraction followed by evaporation and then drying at 100 °C for 30 min, respectively. Crude protein contents were calculated from nitrogen contents (N × 6.25) obtained by the Kjeldhal method. All proximate analyses were performed in duplicate; mean values and coefficient of variation of the residual (cvr, between 2% and 4%) were calculated. Starch content was determined after its enzymatic conversion to glucose and use of glucose-peroxidase-ABTS reagent (Mestres et al., 1993); two to four replications were performed leading to a cvr of 2%. Amylose content was measured in duplicate from the energy of amylose/lyso-phospholipid complex formation using differential scanning calorimetry according to Mestres et al. (1996a); the cvr was 2%.

Damaged starch was assayed in duplicate (with a cvr of 5−7%) by the susceptibility of starch to glucoamylase degradation at 37 °C (Mestres et al., 1993).

α-Amylase activity was determined colorimetrically by using the dyed amylase substrate, Phadebas amylase test food (PATF) reagent (Pharmacia). Amylases were first extracted from 2-g ground sample in 50 mL of 0.5% NaCl (w/v) under constant agitation at 20 °C for 60 min. The suspension was then filtered through a fluted filter. One tablet of PATF reagent was suspended in 5 mL of 0.1 M acetate buffer (pH 5.5) at 45 °C for 10 min, and then 1 mL of extracted amylase solution was added. The reaction was performed at 45 °C for 15 min and stopped by adding 2 mL of 1% (w/v) sodium hydroxide. After holding for 15 min at 20 °C, the suspension was filtered through a small paper filter and the extinction was read at 620 nm. A blank, made with 1 mL of 0.5% NaCl instead of enzyme extract, was subtracted. The α-amylase activity of the solution (AS) was then obtained from the standard curve enclosed with the PATF tablets. It was expressed in the European Brewery Convention (EBC) as α-amylase units per milligram dry matter using the following formula:

$$AA = \frac{AS}{SM \times DM} \times 100$$

where AA = EBC α-amylase units per milligram, SM = sample mass (mg), and DM = sample dry matter content (% wb). AA determinations were performed in duplicate with a cvr of 3%.

In vitro protein digestibility was determined in duplicate after hydrolysis with pepsin in potassium phosphate buffer (at pH 2.0) at 37 °C for 2 h and measurement of recovered N (with Kjeldhal method) in sediment; the results were expressed as percentage of initial N (Mertz et al., 1984; Rom et al., 1992).

Fat acidity was determined in duplicate after extraction with toluene [AACC, 1983 (Method 02−03A)]. It was expressed as mg of KOH necessary to neutralize 100 g of dry matter; the cvr was 6%.

The determination of K, Mg, Ca, Zn, Fe, Mn, Na, and Cu was carried out by absorption using a Varian AA 1275 atomic absorption spectrophotometer (Stuffins, 1967). P content was measured by colorimetry as vanadium phosphomolybdate form [AOAC, 1990 (Method 975−03)]. All mineral element determinations were duplicated, and the cvr ranged from 3 to 17%.

Table 4. Classification Table for Fineness Degree of Traditional Market Dry-Milled Whole Maize Flours from Benin

class	fineness classification	median particle size (μm)	market flour samples
I	very fine	<125	1
II	fine	125−170	2, 3, 6, 7
III	coarse	>170	4, 5, 8

Physical Measurements. Flour particle size measurements were performed on 30-g samples using an air-jet sifter (Alpine 200 LS, Duisburg, Germany) with sieves of increasing apertures: 125, 150, 180, 212, 250, and 315 μm. Particle size indexes (PSI) were calculated as the cumulative percentage of particles (expressed on dry matter basis) passing through any sieve. Duplicates were performed, and the cvr was 7−8%.

Thousand kernel weights were determined in quadruplicate (with a cvr of 2%) on 30-g samples and calculated on dry basis. Dent kernel percentage was evaluated by visual examination of 50 kernels. The endosperm vitreousness was determined by the relative ratio of the vitreous endosperm area of 100 kernel cross sections (Louis-Alexandre et al., 1991). The friability index was defined as the PSI at 315 μm sieve for kernels ground using a KT-30 grinder (Falling Number) with fine burr at setting 1 (Mestres et al., 1995); the mean of triplicates and cvr (2%) were calculated.

Flour Laboratory Processing. 100 g of maize grains was successively ground with KT-30 using the same procedure as for the friability test (see above) and with a Cyclotec 1093 sample mill (Tecator) using coarse (1 mm) aperture.

RESULTS AND DISCUSSION

Physicochemical Characteristics of Traditional Market Flours. Producers and consumers consider that the main quality criterion of lifin is particle size. Indeed a great variation (coefficient of variation between sample, cvs, over 10% for the finest sieves) was observed concerning this characteristic between the samples collected in the markets of Cotonou (Table 3). Flour number 1 was the finest, with a median particle size (PS*m*: estimated sieve aperture through which 50% of the sample would pass) less than 125 μm, and flour number 4 was the coarsest with a PS*m* of 200 μm. The eight market lifins can be arranged in three classes on the basis of their PS*m* (Table 4); flours belonging in the very fine class should be preferred by consumers. Particle size of coarsest market lifins of Cotonou appeared similar to that of traditional sorghum flours (PS*m* of 200 μm) obtained by successive pestle-and-mortar and stone milling of dry grains (Müller, 1970). As a comparison, wet-milling produces finer flours with PS*m* less than 50 μm (Sefa-Dedeh, 1989).

Damaged starch content of market lifins appeared relatively high with a mean value of 28% (starch basis);

Table 5. Kernel Physical Properties of the 21 Maize Cultivars

cultivar	1000 kernel weight [tkw, g (db)]	dent kernel percentage (dkp, %)	vitreousness (%)	friability (% db)
Gbaévé	152	0	56	44
Gbogboué	181	6	52	53
Gnonli	177	27	18	66
Gougba	178	9	56	44
Djakpé	238	30	64	48
DMR-ESR-W	227	14	71	40
Poza Rica 7843-SR	266	61	89	37
Pirsabak 7930 SR	201	1	78	39
Sékou 85	247	45	82	39
B.M.L.	237	14	66	41
DMR-ESR-W × 28 Synthetic 1	238	5	69	39
Gbogboué × TZSR-W	219	56	72	41
AB 11	252	69	65	45
AB 12	215	74	53	47
AB 13	247	60	75	38
NH2-SR	225	5	67	40
TZSR-W	229	50	66	39
TZB-SE-SR	238	48	22	51
TZPB-SR	204	23	68	40
Sékou 85 × TZSR-W	250	57	75	41
La Posta	278	74	86	39
mean value	224	35	64	43
cvc (%)[a]	14	73	27	15

[a] Coefficient of variation between cultivars.

Table 6. Kernel Proximate Composition of the 21 Maize Cultivars (All Results Are Expressed in db, except Water Content, which Is Expressed in wb)

cultivar	water content	crude protein (N × 6.25)	starch	amylose	free lipids	ash
Gbaévé	13.4	10.0	73	23.3	4.2	1.26
Gbogboué	13.8	10.8	73	23.0	4.8	1.50
Gnonli	13.5	9.6	76	22.6	4.3	1.30
Gougba	13.6	10.9	74	24.2	4.0	1.18
Djakpé	14.2	9.9	76	23.5	4.7	1.50
DMR-ESR-W	13.4	10.6	73	22.7	4.6	1.01
Poza Rica 7843-SR	13.9	11.2	72	22.3	4.6	1.24
Pirsabak7930 SR	13.5	11.6	73	23.4	4.5	1.18
Sékou 85	12.0	12.0	72	22.6	4.7	1.36
B.M.L.	13.2	11.3	73	22.5	4.5	1.40
DMR-ESR-W × 28 Synthetic 1	14.0	11.0	72	22.8	4.7	1.11
Gbogboué × TZSR-W	14.1	9.4	73	23.3	4.8	1.19
AB 11	14.1	9.9	74	23.1	4.3	1.26
AB 12	13.4	10.6	72	22.9	4.3	1.22
AB 13	14.6	10.5	75	22.3	3.7	1.27
NH2-SR	13.9	10.9	70	23.0	5.2	1.17
TZSR-W	13.9	9.7	72	22.3	4.6	1.17
TZB-SE-SR	13.8	9.1	71	22.0	5.7	1.02
TZPB-SR	14.1	11.0	72	23.5	4.4	1.18
Sékou 85 × TZSR-W	13.9	10.2	73	23.2	5.7	1.27
La Posta	13.9	9.9	73	22.6	5.4	1.22
mean value	13.7	10.5	73	22.9	4.7	1.24
cvc (%)[a]	4	7	2	2	10	10

[a] Coefficient of variation between cultivars.

as a comparison it was between 0 and 5% for dry-milling laboratory prepared maize semolinas passing through a 325 μm sieve (Mestres et al., 1996b). As for particle size, a great variation (cvs of 14%) of starch damaged content was observed for market lifins. However, no clear trend can be drawn in relation with PSm: the coarsest flours may have the highest starch damage value (flour number 8) or one of the lowest (flour number 4).

The proximate composition of market lifins appeared very similar for all eight samples with a cvs less than 5% (Table 3). It can be seen in particular that free lipid content was high (mean value of 4.5% db), confirming that market lifin originated from whole grain.

The fat acidity of lifin samples appeared very high, with a mean value of 350. As a comparison, freshly harvested grain of unquestionable soundness has a fat acidity value under 22, whereas it can reach levels well over 100 in extreme cases of deterioration with storage (Baker et al., 1959; Zeleny, 1964). Lifin samples were stored for 4−6 months before analysis, and some deterioration may have occurred after grinding. Indeed, grinding causes intimate mixing of grain lipid substrate and lipolytic enzymes, leading to rapid lipolysis into free fatty acids (Shearer and Warwick, 1983; Morrison, 1993). This effect was enhanced in lifin samples due to their high lipid content. Their relatively low water content (mean value of 11.6% wb) was insufficient to prevent this degradation as lipolytic enzymes are active even at 10% moisture content (Mecham, 1964).

Physicochemical Characteristics of Kernels. A great variation was observed within the physical attributes of kernels of the 21 maize cultivars (Table 5): coefficient of variation between cultivars was over 10%

Table 7. Kernel Chemical Characteristics of Eight Maize Cultivars

cultivar	fat acidity (mg of KOH/100 g of dry matter)	amylase activity (EBC units/g db)	protein digestibility (%)	mineral content (mg/100 g of dry matter)								
				K	P	Mg	Ca	Zn	Fe	Mn	Na	Cu
Gbaévé	101	41	72.3	329	290	137	15.3	3.2	1.8	0.78	0.60	0.15
Gbogboué	31	63	75.5	413	349	139	15.9	3.5	1.7	0.75	0.75	0.12
Gnonli	41	36	81.3	377	269	110	9.9	2.7	1.7	0.73	0.55	0.14
Gougba	48	41	78.9	308	251	114	14.0	2.8	1.7	0.77	0.50	0.13
DMR-ESR-W	31	53	76.1	298	236	102	7.8	2.1	1.8	0.62	0.55	0.14
Poza Rica 7843-SR	49	103	70.7	319	246	99	10.5	1.9	1.9	0.66	0.75	0.17
Pirsabak 7930 SR	31	53	75.8	304	265	98	8.1	1.7	1.6	1.24	0.90	0.14
Sékou 85	38	110	63.7	405	300	124	4.9	1.9	1.9	0.80	0.60	0.14
mean value	45	63	74.3	344	276	115	10.8	2.5	1.8	0.80	0.70	0.14
cvr (%)[a]	6	3	1	3	5	6	7	3	8	3	17	14
cvc (%)[b]	47	43	7	13	12	13	34	25	6	20	20	10

[a] Coefficient of variation of the residual. [b] Coefficient of variation between cultivars.

Table 8. Characteristics of the Laboratory-Prepared Whole Maize Flours

cultivar	particle size index[a] at different sieve openings (μm)						median particle size (μm)	damaged starch (%)
	125	150	180	212	250	315		
Gbaévé	37	49	54	61	70	84	150	11
Gbogboué	36	51	59	66	73	84	150	7
Gnonli	60	71	76	82	87	94	<125	3
Gougba	34	42	47	56	61	72	200	11
Djakpé	31	40	46	53	60	75	200	13
DMR-ESR-W	29	39	43	49	57	72	210	10
Poza Rica 7843-SR	32	42	51	58	66	84	180	12
Pirsabak7930 SR	30	37	42	49	56	70	210	11
Sékou 85	33	45	53	63	70	84	160	7
B.M.L.	37	44	50	57	64	77	180	12
DMR-ESR-W × 28 Synthetic 1	31	38	45	52	61	74	200	16
Gbogboué × TZSR-W	40	50	56	62	70	83	150	11
AB 11	37	47	53	59	67	79	160	12
AB 12	40	49	54	61	68	81	150	9
AB 13	32	39	45	51	58	73	210	13
NH2-SR	27	34	40	46	54	68	230	15
TZSR-W	29	38	44	50	57	72	210	16
TZB-SE-SR	34	61	69	74	80	89	140	6
TZPB-SR	28	35	41	47	53	68	230	15
Sékou 85 × TZSR-W	28	36	42	49	56	71	210	16
La Posta	21	30	35	41	49	62	250	19
mean value	34	44	49	56	63	77	–	12
cvc (%)[b]	25	22	20	17	15	10	–	33

[a] Cumulative percentage of particles passing through the sieve. [b] Coefficient of variation between cultivars.

for all physical attributes and was particularly important for dent kernel percentage (DKP, 73%). Local ecotypes had null or very low DKP whereas new cultivars might have very low (Pirsabak 7930 SR for example) or high DKP (AB 12 and La Posta for example). Four of the five local ecotypes had small grains with thousand kernel weight (tkw) less than 200 g (db), whereas most of the new cultivars had a tkw between 200 and 250 g (db); no cultivar had a tkw close or above 300 g (db), a value that is currently observed for hybrids (Peplinski et al., 1992). This was in agreement with previous results (Mestres et al., 1991, 1995). Concerning vitreousness, local ecotype grains could be classified as floury or medium vitreous (Louis-Alexandre et al., 1991), and most grains from new cultivars belonged in vitreous or very vitreous classes. However the cultivar TZB-SE-SR that had been especially designed to have soft endosperm (SE) had floury grains, and AB 12 kernels appeared medium vitreous. Similarly, the five local ecotypes had friable to very friable grains (Mestres et al., 1995) whereas most of the new cultivars, except TZB-SE-SR, AB 11, and AB 12, had medium coherent to coherent grains. Gnonli had the least vitreous and most friable grain.

Much less variation was observed for the proximate composition of maize grains (Table 6). Protein content ranged from 9.1 to 12.0% (db) whereas it has been already observed African cultivars with grains having a protein content as low as 7.4% or, at the opposite end, as high as 14.1% (Mestres et al., 1991, 1995). Starch and amylose contents were very close for all cultivars, at 73 and 23% (db), respectively. On a starch basis, amylose content varied from 29.7 to 32.8%. These values are completely in agreement with those measured by Morrison et al. (1984), who found amylose content of starches extracted from 20 tropical normal maize cultivars ranging from 28.7 to 32.5%, except one sample having 25.8% amylose content. It is thus confirmed that the range of amylose content is not wide for tropical maize cultivars, contrary to what is observed for tropical sorghum grains, for example (Fliedel, 1994). Little higher variations were observed for free lipid and ash contents; TZB-SE-SR, Sékou 85 × TZSR-W, and La Posta grains having free lipid content over 5% (db), Gbogboué and Djakpé grains having ash content of 1.50% (db). Protein and free lipid contents revealed that whole maize grains had proximate composition very close to that of traditional market flours (Table 3).

Some other chemical attributes were also determined on eight grain samples: four from local ecotypes, four from new cultivars (Table 7). Gbaévé grains had the highest fat acidity value (101), but all samples had a

Table 9. Correlation Matrix between Physicochemical Characteristics of Kernels and of Laboratory-Prepared Flours

	tkw[a]	dkp[b]	vitreousness	friability	crude protein	starch	amylose	free lipids	ash	PSI-150 μm	PSI-315 μm
dkp	0.65**										
vitreousness	0.55**	0.18									
friability	−0.49*	−0.08	−0.88***								
crude protein	0.04	−0.37	0.50	0.46*							
starch	−0.22	−0.02	−0.19	0.44*	−0.23						
amylose	−0.49*	−0.39	0.08	−0.01	0.14	0.24					
free lipids	0.41	0.17	−0.01	−0.03	−0.25	−0.50*	−0.24				
ash	−0.07	−0.02	0.06	0.25	0.17	0.50*	0.15	−0.16			
PSI-150 μm	−0.43*	0.01	−0.83***	0.85***	−0.40	0.30	−0.23	−0.10	0.11		
PSI-315 μm	−0.31	0.03	−0.60**	0.65**	−0.25	0.24	−0.30	−0.09	0.21	0.92***	
damaged starch	0.50*	0.18	0.68***	−0.73***	0.04	−0.26	0.12	0.20	−0.14	−0.88**	−0.83***

[a] Thousand kernel weight. [b] Dent kernel percentage. * Significant at 0.05 level. ** Significant at 0.01 level. *** Significant at 0.001 level.

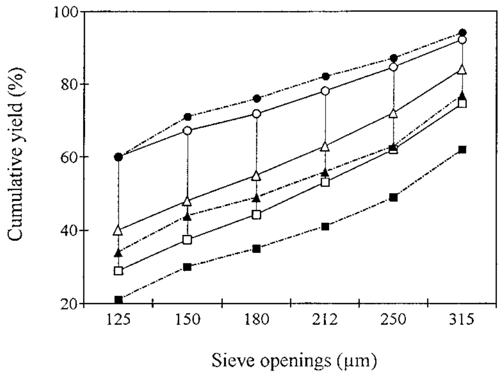

Figure 1. Particle size distribution of market flours (open symbols) and laboratory-prepared whole maize flours (solid symbols). Results are expressed as cumulative percentages of particles passing through the sieves: ■, coarsest flour; ▲, mean; ●, finest flour.

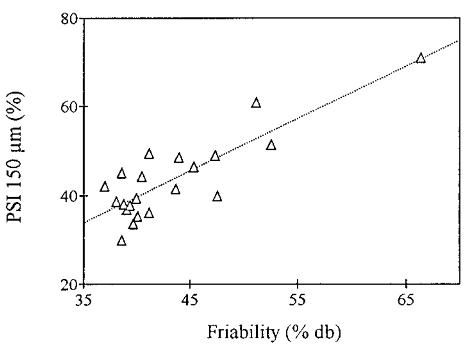

Figure 2. Relationship between kernel friability and particle size index at 150 μm of laboratory-prepared whole maize flour.

fat acidity level over 22; therefore, none could be considered of unquestionable soundness (Baker et al., 1959). Nevertheless, fat acidity of Gbaévé grains was far from the values observed for traditional market flours (Table 3). The amylase activity of grains from new cultivars seemed to be higher than that of the local ecotypes; but this difference has to be confirmed on further samples. On the contrary, protein digestibility was very high and similar for all maize samples. Indeed maize grain proteins are known to have very high digestibility (Mertz et al., 1984).

Concerning the content of mineral elements, mean value (Table 7) were close, for the eight samples, to those indicated in food composition tables (FAO, 1970; Scherz and Senser, 1994), except for Na whose content was ten times lower. Macromineral contents of maize cultivars were low, like for other cereal grains. Micromineral contents (especially for Zn and Fe) were particularly low compared to that of small grain cereals (Wright, 1987; Scherz and Senser, 1994); this deficiency could cause

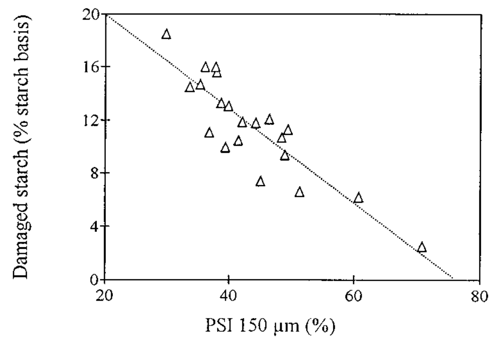

Figure 3. Relationship between particle size index at 150 μm of laboratory-prepared whole maize flour and its damaged starch content.

Table 10. Correlation Matrix between Principal Component Axes and Physicochemical Characteristics of Kernels and of Laboratory-Prepared Flours

	first component (40.2%)[a]	second component (20.1%)	third component (12.8%)
tkw[b]	−0.61	−0.61	0.36
dkp[c]	−0.17	−0.69	0.52
vitreousness	−0.87	0.16	0.29
friability	0.92	−0.08	0.04
crude protein	−0.38	0.52	−0.07
starch	0.45	0.34	0.69
amylose	−0.04	0.75	−0.07
free lipids	−0.21	−0.61	−0.31
ash	0.22	0.32	0.68
PSI-150 μm	0.95	−0.23	−0.01
PSI-315 μm	0.83	−0.23	0.08
damaged starch	−0.88	−0.01	0.08

[a] Percentage of variation explained by the component. [b] Thousand kernel weight. [c] Dent kernel percentage.

severe diseases for people consuming maize grain products as primary staple food (like in South of Benin), particularly for young children (Scrimshaw, 1991; Dupin et al., 1992). All mineral element contents, except for Fe, presented coefficient of variation between cultivars over 10%; local ecotypes generally had higher mineral element contents than new cultivars. However Sékou 85, a new cultivar, had the highest content of K, P, and Fe, while Pirsabak 7930 SR presented the highest content of Mn and Na.

Grinding Behavior of Corn Kernels. Median particle size of the 21 flours prepared in the laboratory (Table 8) was between less than 125 μm and 250 μm. It was close to the values observed for market flours produced using attrition disc mills (Table 3). Moreover particle size repartition curves of laboratory-prepared flours were similar to those observed for market flours (Figure 1). This confirmed that the procedure used in the laboratory for producing whole maize grain flours

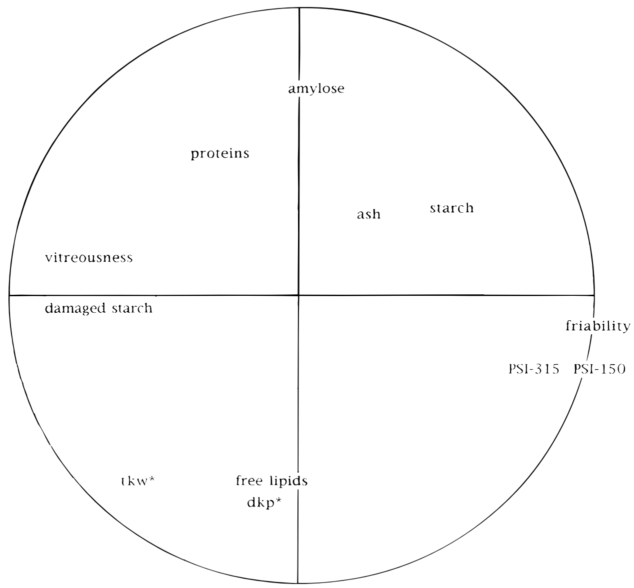

Figure 4. Correlation circle of the 12 normalized variables of the physicochemical attributes of maize kernels: first and second components as first and second axes, respectively. Tkw is thousand kernel weight, dkp is dent kernel percentage, PSI-150 and PSI-350 are particle size indices measured with 150 and 315 μm sieves, respectively.

fitted with the traditional procedure used in West African countries.

Gnonli gave the finest flour (belonging in very fine class, Table 3), and La Posta the coarsest one. Half of the new cultivars gave flours having a median particle size over 200 μm, while none of the local ecotypes gave such coarse flour; no market lifins were so coarse (Table 3). Among new cultivars, TZB-SE-SR gave the finest flour. It belonged to the fine flour class, as did flours from four other new cultivars. We observed highly significant correlations between particle size repartition of the flours (for example, PSI for 150 and 315 μm sieve) and grain friability or vitreousness (Table 9). The more friable and floury the grain was, the finer the flour it gave (Figure 2). But the other physical or chemical grain attributes were not correlated with flour particle size (except tkw that was correlated at 0.05 level with PSI at 150 μm sieve). This confirmed previous results obtained with industrial milling processes (Mestres et al., 1995).

A great variability was also observed for the damaged starch content of the 21 flours. Gnonli flour had the lowest damaged starch content, and La Posta flour had the highest. Indeed, highly significant negative correlation coefficients were observed between flour PSI and damaged starch content (Table 9). Damaged starch content was also positively correlated with endosperm vitreousness and negatively with grain friability. This was in agreement with previous results on maize (Szaniel et al., 1984; Mestres et al., 1996b) and the general relationship found for other cereals such as wheat (Williams, 1967; Bakhella et al., 1990; Nemeth et al., 1994). Moreover it is noteworthy that finer flours had lower damaged starch content (Figure 3), even if there is a better contact between enzyme (in solution) and substrate (dispersed) during the measurement of damaged starch for fine flours.

But damaged starch contents of the laboratory prepared flours were at least half as high as the values measured for the market flours (Tables 3 and 8). This might be due to the processing procedures: in Africa, the product is passed 3−5 times in the attrition disc mills to obtain a flour of the desirable fineness (Agossou

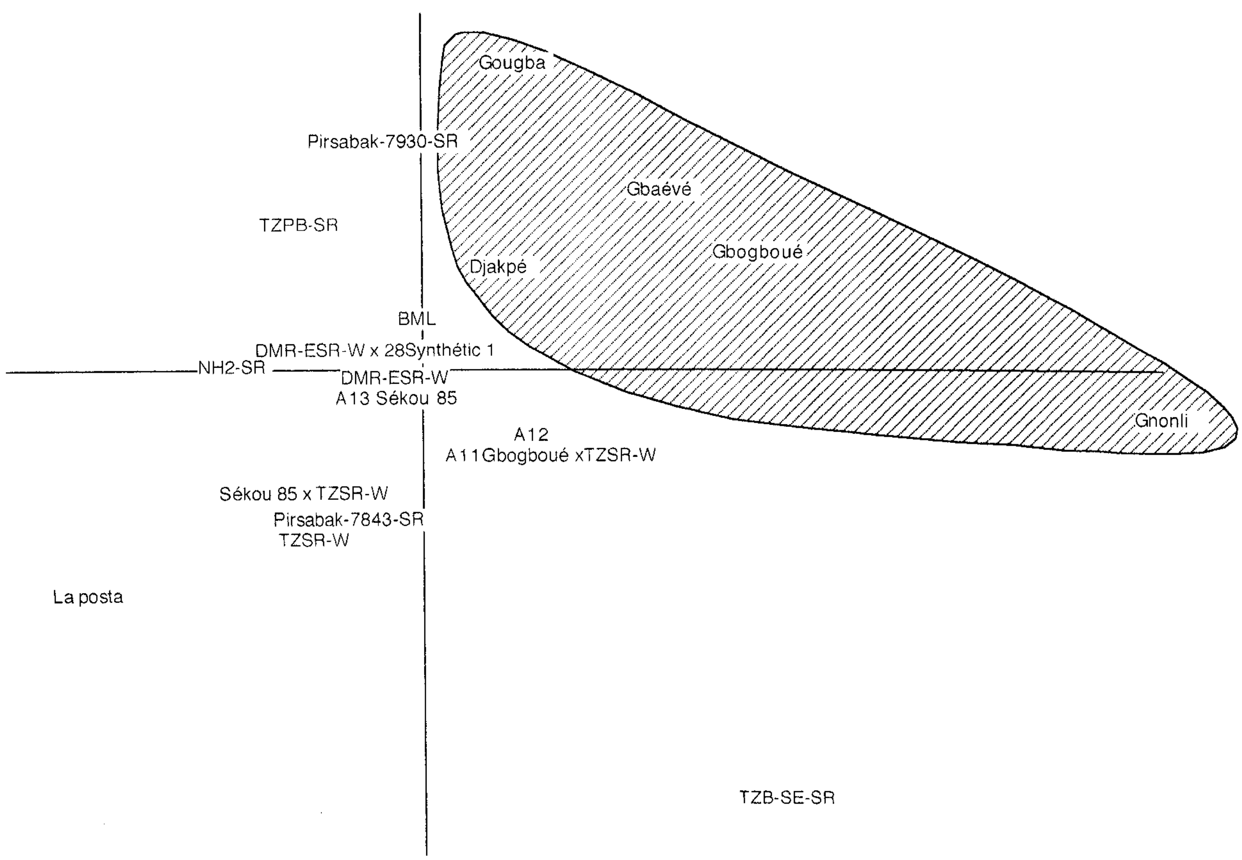

Figure 5. Sample plot with first and second components as first and second axes, respectively. Hatched area contains all local maize ecotypes.

et al., 1986; Tchamo, 1993). These successive attritions might have enhanced damaging of starch compared to the laboratory methodology that involves only two passes into two different grinders.

Principal Component Analysis. A principal component analysis was performed with the 12 normalized variables of the physicochemical attributes of the 21 maize grain samples. The first three components accounted for 73% of the variation (Table 10); the following ones described percentages of variance too low to be discussed here. The first principal component was highly positively correlated with grain friability and particle size analysis of flours and negatively correlated with damaged starch content of flours and grain vitreousness (Table 10, Figure 4). Indeed, all of these attributes were highly correlated (Table 9). Thus the first component represented the mechanical behavior and endosperm texture of kernels and their consequences on the quality of laboratory-prepared whole maize flours. The second principal component is positively correlated with amylose content and negatively correlated with free lipid content. In fact, the actual variability of amylose content was very low (Table 6), and its role in this component was enhanced as all variables were normalized. Protein content and tkw appeared in an intermediate position between the first and second components. The third principal component was highly positively correlated with grain ash content (Table 10). Dent kernel percentage had an intermediate position between second and third principal components. Starch content variability was distributed in the three components. The same remark as for amylose can be made for this last variable.

The 21 maize samples were plotted on a plane with the percentages of variation associated with the first and second components (Figure 5). This representation accounted for 60% of total variation; the other representations (including the third component) were less conclusive (they confirmed the preceding one) and will not be discussed. Local ecotypes were clearly located in the first quarter of the representation: indeed, they presented high friability and low vitreousness, giving relatively fine flours with low damaged starch levels (to the right of the first component) and with also low dent kernel percentages (above the second component). All new cultivars, except TZB-SE-SR, could be arranged in one group. Among new cultivars, only four were located to the right of the first component, those giving fine flours (with median particle size close to 150 μm). TZB-SE-SR was positioned at the right bottom of the plot: it was close to local ecotypes concerning the first component but differed by high tkw, dent kernel percentage, and free lipid content (second component). In addition, one could remark that the cross Gbogboué × TZSR-W had an intermediate position between its two parents.

This classification of maize samples is based on the characterization of their phenotype. Indeed, the relative effect of genotype and environment was not taken into account in this study. But, it has been shown that maize grain chemical composition, particularly its protein and lipid contents, varies more with environmental conditions than with genotype (Arnold et al., 1977; Kniep and Mason, 1991; Shumway et al., 1992), whereas maize kernel physical properties, such as hardness and milling behavior, are much more influenced by genotype than by environmental conditions (Shumway et al., 1992; Chaurand et al., 1994). Endosperm texture (vitreousness or density) seems to have an intermediate position, being equally influenced by both factors (Shumway et al., 1992). Thus, at least the first axis of the principal component analysis, that mainly reflects physical characteristics and particularly milling behavior of kernels, is likely an indication of genotype kernel characteristics. This may also be true for dent kernel percentage, which is a physical attribute currently used to classify maize cultivar. Furthermore, as environmental conditions were very similar for all maize samples, it is also likely that the second axis is governed mainly by genotype.

CONCLUSION AND PERSPECTIVES

The nutritional properties (protein digestibility and mineral contents) of kernels from local ecotypes or new cultivars were found very similar. But, based on their physicochemical characteristics, maize grains from local ecotypes were arranged in one group completely separated from another group made with most new cultivars. Grain physical and mechanical characteristics play the main role in this classification: local ecotypes have generally small and non-dented kernels with floury and soft endosperm giving fine flours similar to traditional market flours while on the contrary most new cultivars give coarse or very coarse flours. This partly explains the inadequacy of the new cultivars to farmers' requirements and the failing of their adoption.

Further study will report the measurement of the quality of thick pastes made with the flours from local ecotypes and new cultivars.

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