The Distribution of Lipids in the Germ, Endosperm, Pericarp and Tip Cap of Amylomaize, LG-11 Hybrid Maize and Waxy Maize

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ABSTRACT

The quantitative distribution of 23 acyl lipid classes and unsaponifiable matter in kernels of amylomaize, LG-11 hybrid maize and waxy maize is described. LG-11 and waxy maize were normal (oil content) varieties, containing 4.9% and 5.1% lipid, respectively, while amylomaize (9.3% lipid) was a high oil variety. The distribution of kernel lipids was 76-83% in germ, 1-2% in pericarp, 1% in tip cap, 1-11% in starch, and 13-15% in aleurone plus the nonstarch fraction of the starchy endosperm. Germ contained 39-47% lipid, which was mostly triglyceride (TG), with some steryl esters (SE) and diglycerides (DG), and small amounts of glycolipids (GL) and phospholipids (PL). Aleurone lipids appeared to be TG with some free fatty acids (FFA) and SE. The other nonstarch lipids in starchy endosperm were FFA with very small amounts of SE, DG, GL and PL. The starches had a little surface lipid (FFA) and true (internal) starch lipid (FFA, lyso-PL) in quantities roughly related to amylose content (amylomaize = ca. 73% amylose, 1.0% lipid; LG-11 = 23% amylose, 0.7% lipid; waxy maize = < 5% amylose, 0.2% lipid). Pericarp lipids (0.8-2.5%) were mainly unsaponifiable matter, the acyl lipids being TG, SE, DG and FFA. Tip cap lipids (2.5-2.9%) had more TG, GL and PL than pericarp lipids, but were otherwise similar. Pericarp lipids and endosperm nonstarch lipids appeared to have suffered extensive degradation at some time during kernel development or after harvesting, while lipids in starch, germ and tip cap were evidently unaffected. FFA and lyso-PL are regarded as normal components of maize starch (rather than degradation products) and may occur as amylose inclusion complexes.

INTRODUCTION

A logical starting point for a systematic study of cereal lipids would be the quantitative distribution of all lipid classes in the principal parts of the caryopsis. We are aware of no such data in the literature for any cereal, although there is information on the distribution of total lipids in all cereals, and on sterols, tocopherols, carotenoids and some glycerides in maize, wheat and rice (1).

In view of the importance of maize lipids, and the fact that the maize kernel is large and therefore comparatively easy to dissect, we decided to study the distribution of lipids in maize. We used commercial samples of amylomaize, LG-11 hybrid maize and waxy maize, and determined the distributions of 23 acyl lipid classes in the pericarp, tip cap, germ, endosperm and starch. Our results, reported in this paper, complement previous analyses of the

TABLE I

Total Lipid Content, as Fatty Acid Methyl Esters, of Dissected Maize Kernels

	Percentage of kernel dry wt.	Total lipid (% of dry wt.)		Percentage fatty acid composition[b]					
		Hydrolysis[a]	Solvent[b]	16:0	18:0	18:1	18:2	18:3	Others
Amylomaize									
Pericarp	7.8	0.19	0.24	21.8	5.8	23.9	39.5	6.6	2.5
Endosperm, total	74.7	2.42		25.1	3.6	25.1	43.7	2.6	
Endosperm, NSL + aleurone[c]			1.77	18.3	1.9	27.5	49.6	2.7	
Endosperm, NSL − aleurone[c]			0.69	22.4	3.6	21.3	49.4	3.3	
Endosperm SL[c]			0.65	38.5	4.3	20.0	36.0	1.2	
Starch		0.86	0.82	36.2	4.7	20.2	37.8	1.2	
Germ	15.0	37.23	33.74	12.0	2.0	29.3	55.0	1.7	
Tip cap	2.5	1.75	1.76	16.9	4.0	32.9	40.1	6.1	
LG-11									
Pericarp	4.2	0.24	0.29	24.7	5.2	21.1	45.8	3.1	
Endosperm, total	86.0	1.02		24.7	1.9	15.6	53.5	4.3	
Endosperm, NSL + aleurone[c]			0.57	16.6	2.1	19.0	57.8	4.5	
Endosperm, NSL − aleurone[c]			0.29	24.0	1.7	11.6	58.6	4.1	
Endosperm, SL[c]			0.45	31.4	1.1	11.1	53.8	2.7	
Starch		0.56	0.51	36.8	1.8	10.1	47.9	3.5	
Germ	8.4	40.60	38.71	11.0	1.4	24.1	62.8	0.7	
Tip cap	1.4	2.03	1.62	22.1	2.6	20.0	49.2	6.0	
Waxy maize									
Pericarp	6.6	0.22	0.20	19.4	4.5	21.4	40.3	3.0	11.4
Endosperm, total	81.0	0.80		27.5	2.0	15.4	49.9	5.3	
Endosperm, NSL + aleurone[c]			0.73	24.6	1.8	14.0	53.4	6.2	
Endosperm, NSL − aleurone[c]			0.45	33.3	2.2	10.0	50.6	4.0	
Endosperm, SL[c]			0.12	29.5	4.1	23.0	40.2	3.3	
Starch		0.14	0.14	35.5	4.4	23.2	35.5	1.5	
Germ	10.8	35.66	35.57	10.6	1.5	20.3	66.3	1.3	
Tip cap	1.6	1.96	1.71	17.4	2.8	27.9	49.4	2.6	

[a]By acid hydrolysis, extraction and methanolysis.

[b]By direct solvent extraction and methanolysis – except total endosperm fatty acids which were by hydrolysis and methanolysis.

[c]NSL = nonstarch lipids, SL = starch lipids.

total lipids (2-6), total fatty acids (3,5,7-10), carotenoids (11) and tocopherols (12) in dissected fractions of maize kernels.

EXPERIMENTAL PROCEDURES

Materials

LG-11 hybrid maize was provided by Dr. R. Drapron, Station de Biochimie et Physico-Chemie des Céréales, I.N.R.A. au C.E.R.D.I.A., Massy, France. A commercial sample of waxy maize was obtained from Dr. D. Pedrina, Fabbriche Riunite Amido Glucosio Destrina, S.P.A., Milan, Italy, and amylomaize from Dr. G.W. Deardorff, American Maize Products Co., Urbana, IL. Reference lipids were prepared from wheat flour (13) or were purchased from Sigma London Chemical Co., Ltd., (Poole, England).

Maize kernels were steeped for 3 hr in 0.1% sodium metabisulfite solution at 50 C before dissection. Endosperm, pericarp and tip cap fractions were air-dried and milled to pass a 100 mesh sieve. Endosperm minus aleurone was prepared by cutting off the pericarp, germ, and the aleurone layer together with some adjacent starchy endosperm from dry kernels. Germ tissue was finely sliced before analyses, with precautions to recover lipid from the scalpel blade.

Starch was prepared from milled endosperm which had been soaked in 0.1% sodium metabisulfite at 50 C for 16 hr. Crude starch was separated by centrifuging at 108,000 x g for 1 hr, and LG-11 starch, essentially free from protein, was obtained by repeated washing and centrifuging. Amylomaize and waxy maize starches required additional steeping at 25 C for 24 hr in Pronase dissolved in 0.2 M phosphate buffer at pH 7.4. The starches were washed in distilled water, air-dried, and ground to pass a 120 mesh sieve.

Methods

Moisture was determined by drying to constant weight in a vacuum oven at 70 C (minimum 24 hr). All results are expressed on a dry weight basis.

Total acyl lipid was determined as fatty acid methyl esters (FAME) by gas liquid chromatography (GLC) after acid hydrolysis and methanolysis of an aliquot of hydrolyzate lipid, using heptadecanoic acid as internal standard (14). The optimum hydrolysis times were 45 min for endosperm and starch, 360 min for germ, and 90 min for bran and tip cap.

Acyl lipids in aliquots of solvent extracts and on thin layer chromatography (TLC) plates were quantified as FAME, and, in the case of phospholipids, by phorphorus distribution (14).

Unsaponifiable lipids were determined by saponifying 100 μl aliquots of lipid extracts with 2 ml of 1N KOMe in MeOH, in tubes sealed under nitrogen and heated at 100 C for 3 hr. After cooling, water (2 ml), diethyl ether (2 ml) and light petroleum (0.6 ml) were added, and the tubes were then well shaken and centrifuged. The upper phase was evaporated dry under nitrogen and redissolved in 1.0 ml chloroform. Aliquots (200 or 300 μl) were then evaporated in tarred aluminum foil dishes (ca. 20 mg) and weighed on a Cahn electrobalance.

Optimum conditions for the solvent extraction of lipids were different for each tissue. Endosperm nonstarch lipids were obtained by extracting five times with 10 vol water-saturated n-butanol (WSB) at room temperature, with a total extraction time of 30 min (14). Lipids in purified starch, or the residual starch lipids after extraction of nonstarch lipids, were extracted five times with 10 vol WSB at 90-95 C, with a total extraction time of 6 hr. Bran and tip cap lipids were similarly extracted with hot WSB for 3 hr. Germ was sliced with a scalpel under solvent, and extracted ten times with 5 vol chloroform/methanol (1:1), and the residue was finally extracted with WSB at 90 C for 3 hr. Solvent extracts were concentrated by rotary vacuum evaporation, and the lipids purified by Bligh and Dyer partitioning (15). Lipids were analyzed by silicic acid column chromatography, TLC, and GLC using methods described in previous papers (13,14,16). The data in Tables I-III are accurate to better than ± 3%, and in most cases to better than ± 1%.

RESULTS

Total Lipids

The weights of the dissected kernel fractions (Table I) show that LG-11 and waxy maize were quite typical, but amylomaize had more pericarp and germ (and less endosperm) than is usual (1,6).

The hydrolyzate lipid and extractable lipid contents (as FAME) of the pericarp and tip cap samples (Table I) were much lower than published lipid contents, but when converted into total lipids, including unsaponifiable matter, the results (Table II) fell within the normal ranges (1,6). Blessin (2) reported 9.5% lipid in the tip cap of five yellow corn hybrids, but the tip cap was known to be contaminated with germ.

More lipid was found in the germ of all three types of maize (Tables I, II) than is usually reported (1,6). This is attributed to the greater efficiency of the anlaytical procedures used in the present study rather than to abnormally high lipid contents.

Endosperm lipids are located in three distinct regions – the aleurone layer, the nonstarch fraction of the starchy endosperm, and inside the starch granules. Hydrolyzate lipid values (Table I) are a measure of the total endosperm lipids. Starch lipid values can only be determined from washed starch, or by first removing the aleurone and other nonstarch lipids from finely milled endosperm samples and then extracting the starch lipids with hot WSB, as is done with wheat flour (14).

Since it was not possible to remove the aleurone layer without the risk of causing unacceptable damage to lipids (e.g., by alkali dehulling), aleurone lipid in amylomaize was determined by difference from complete endosperm and from endosperm minus aleurone and some adjacent starchy endosperm (Table I). This approach was less successful with LG-11 and waxy maize, which contained ca. 280 mg aleurone lipid (as FAME) per 100 g endosperm, compared with ca. 1000 mg in amylomaize. Scanning electron micrographs showed that the aleurone cells in LG-11 and waxy maize were isodiametric, while those in amylomaize were radially elongated and approximately twice as large. Thus, it would be reasonable to attribute the greater aleurone lipid content of amylomaize to its larger proportion of aleurone cells, without necessarily invoking a much higher percentage of lipid within aleurone cells.

Amylomaize also had more lipid than LG-11 or waxy maize in the nonstarch and starch lipid fractions of its starchy endosperm. Starch lipid content decreased with amylose content (ca. 70, 23 and $<$ 5% amylose, respectively), but was obviously not directly related. This agrees with earlier results of Acker and Schmitz, although their results were generally higher (17).

The total endosperm lipid contents (Table II) were significantly higher than previously reported (2-6). This was probably due to the improved analytical techniques used in the present study, and to the inclusion of starch lipids which were not quantified in previous studies.

The mean dry weights of the kernels were: amylomaize = 249 mg, LG-11 maize = 250 mg, and waxy maize = 284 mg, and the total lipid contents, calculated from Table III, were respectively 9.33, 4.87 and 5.17%. Amylomaize was thus a high oil variety on account of its greater germ weight and higher lipid content in pericarp and endosperm, while LG-11 and waxy maize had normal lipid contents.

Germ Lipids

Apart from differences in quantities of unsaponifiable matter, the germ lipids were very similar in all three types of maize (Table II). The principal lipids were triglycerides (70-85% of total), 1,2-diglycerides and steryl esters. The unsaponifiables, which included a large proportion of free sterols, were not analyzed in detail.

The high proportions of phosphatidyl choline and phosphatidyl inositol seem to be characteristic of germ lipids in maize (Table II) and other cereals (18-21), but the amount of phosphatidic acid in amylomaize germ seems unusually high.

Endosperm Lipids

Information on the aleurone lipids is imprecise because they could only be determined by difference, and the endosperm-minus-aleurone material did not represent the whole of the starchy endosperm. Best results were obtained for amylomaize, but the same principal features can be seen in LG-11 and waxy maize (Table II).

Aleurone contained most of the endosperm triglyceride, a substantial part of the steryl ester, diglyceride, free fatty acid (amylomaize only), monoglyceride (amylomaize and waxy maize), phosphatidyl choline and phosphatidyl inositol. There appeared to be little or no glycolipids in the aleurone.

The aleurone lipids resembled germ lipids, as might be expected, because they have similar functions during germination (1). In wheat the aleurone lipids are almost the same as the germ lipids (22) and both have more phospholipids than the corresponding tissues in maize.

The nonstarch lipids (excluding aleurone) were mostly free fatty acids with only small amounts of other nonpolar lipids, glycolipids and phospholipids. This is very unusual, and immediately suggests extensive lipolysis of the diacyl glycerides and triglycerides usually found in the nonstarch lipids of wheat and other cereal endosperm flours (1). Steeping the kernels for dissection did not cause lipolysis, because the same results were obtained from dry dissected kernels. Thus, lipolysis must have occurred during development and drying out of the kernels, or high levels of free fatty acids are a normal feature of the nonstarch lipids in maize endosperm.

Lysophospholipids are the major lipids in wheat and other cereal starches (1,17). They resist extraction with cold WSB, but can be recovered by prolonged extraction with hot WSB(14). The corresponding lipids in maize starch are free fatty acids and lysophospholipids (Table II). However, a small proportion of the free fatty acids could be extracted from washed maize starches with cold WSB, which indicates that these fatty acids are either nonstarch lipids adsorbed onto the surfaces of the starch granules, or they are leaky starch lipids from the peripheral regions of the granules (in which case perhaps there ought to be some leaky lysophospholipids too). The concept of adsorbed, nonstarch free fatty acids is supported by the higher ratio of free fatty acids: lysophospholipids in the pure (washed) starches which had not been exposed to cold WSB, and by the fact that free fatty acids with almost no lysophospholipids were found in pure waxy maize starch but not in the corresponding starch fraction of the endosperm (Table II).

Pericarp and Tip Cap Lipids

Pericarp lipids contained large amounts of unsaponifiable matter (Table II), which was mostly sterols and ali-

TABLE II

Composition of Lipids in Amylomaize, LG-11 Maize and Waxy Maize Kernels (mg Lipid/100 g Dry Wt.)

Amylomaize

Lipid	Endosperm: Nonstarch + aleurone	Endosperm: Nonstarch - aleurone	Endosperm: Aleurone (by difference)	Endosperm: Starch	Pure starch	Germ	Pericarp	Tip cap
Steryl ester	53	24	29	5	9	450	59	73
Triglyceride	898	92	806	14	16	32854	115	1308
Diglyceride	64	45	19	4	16	2013	31	76
Free fatty acid	657	471	186	447	650	694	38	182
Monoglyceride	19[a]	10[a]	9[a]	9	13	169[a]	7[a]	27[a]
Estd. steryl glycoside	15	13	7	8	13	258	14	29
Monogalactosyl monoglyceride	{11	{19	{-8	—	—	{173	{6	15
Monogalactosyl monoglyceride				22	18			10
Digalactosyl diglyceride	10	9	1	—	—	129	7	21
Digalactosyl monoglyceride	13	24	-11	34	17	213	10	16
N-acyl phosphatidyl ethanolamine	trace			—	—	73	5	10
N-acyl lysophosphatidyl ethanolamine	{2	2		—	—	—	—	trace
Diphosphatidyl glycerol				—	—			
Phosphatidyl glycerol	6		6	—	—	19	{2	8
Phosphatidyl ethanolamine	8		8	—	—	174		8
Phosphatidyl choline	31	8	23	—	—	376	7	29
Phosphatidyl inositol	9	2	7	—	—	229	3	19
Phosphatidic acid	12	3	9	—	—	333	5	14
Lysophosphatidyl glycerol				4	7			
Lysophosphatidyl ethanolamine	4[b]		4[b]	17	16	11[b]	1[b]	3[b]
Lysophosphatidyl choline	29	16	13	166	183	9	7	16
Lysophosphatidyl inositol				4	6			16[c]
Nonpolar lipids	1691	642	1049	479	704	36180	250	1666
Glycolipids	49	65	-16	64	48	773	37	91
Phospholipids	101	31	70	191	212	1224	30	123
Unsaponifiable lipids	47	21	26	29	67	9095	2143	1036
Total lipids	1888	759	1129	763	1031	47272	2460	2916

LG-11 Maize

Lipid	Endosperm: Nonstarch + aleurone	Endosperm: Nonstarch - aleurone	Endosperm: Starch	Pure starch	Germ	Pericarp	Tip cap
Steryl ester	49	14	4	3	818	120	253
Triglyceride	344	45	8	5	36953	163	1184
Diglyceride	33	10	3	3	1244	26	89
Free fatty acid	133	168	290	380	305	7	345
Monoglyceride	7[a]	5[a]	11	12	39[a]	4[a]	53[a]
Estd. steryl glycoside	7	13	6	7	73	7	48
Monogalactosyl monoglyceride	{12		{11		{128	9	26
Monogalactosyl monoglyceride						3	25
Digalactosyl diglyceride	12		9		436	2	56
Digalactosyl monoglyceride	12		8		172	6	22
N-acyl phosphatidyl ethanolamine	3		—	—	110	11	15
N-acyl lysophosphatidyl ethanolamine	{1		—	—	{18	{3	
Diphosphatidyl glycerol			—	—			
Phosphatidyl glycerol	1		—	—	36	{4	
Phosphatidyl ethanolamine	1		—	—	194		27
Phosphatidyl choline	3		—	—	748	8	41
Phosphatidyl inositol	3		—	—	247	7	32
Phosphatidic acid	1		—	—	77	2	24
Lysophosphatidyl glycerol			4	6		{3[b]	
Lysophosphatidyl ethanolamine			16[b]	17[b]			
Lysophosphatidyl choline	17		220	226	23	4	28
Lysophosphatidyl inositol			8[c]	8[c]			18[c]
Nonpolar lipids	566	242	316	403	39359	320	1924
Glycolipids	43	38	34	23	809	27	177
Phospholipids	30	36	248	257	1453	42	185
Unsaponifiable lipids	72	32	—	—	1916	451	305
Total lipids	711	348	598	683	43537	840	2591

Waxy maize

Lipid	Endosperm: Nonstarch + aleurone	Endosperm: Nonstarch - aleurone	Endosperm: Starch	Pure starch	Germ	Pericarp	Tip cap
Steryl ester	32	4	3	7	382	45	104
Triglyceride	269	32	33	12	32992	102	1197
Diglyceride	11	4	3	6	542	14	178
Free fatty acid	397	384	30	105	237	59	400
Monoglyceride	8[a]	2[a]	1	5	123[a]	9[a]	35[a]
Estd. steryl glycoside	11	5	1	3	404	11	76
Monogalactosyl monoglyceride		{4	{1	{1	{178		{25
Monogalactosyl monoglyceride							
Digalactosyl diglyceride		2	1	2	158		32
Digalactosyl monoglyceride		5	2	3	298		29
N-acyl phosphatidyl ethanolamine	1	1	—	—	117	5	
N-acyl lysophosphatidyl ethanolamine	{1	{1	—	—	{30	{1	
Diphosphatidyl glycerol			—	—			
Phosphatidyl glycerol	trace	trace	—	—	27	2	{3
Phosphatidyl ethanolamine	1	1	—	—	49	1	
Phosphatidyl choline	1	1	—	—	578	5	7
Phosphatidyl inositol			—	—	397	2	15
Phosphatidic acid	trace	trace	—	—	59	7	17
Lysophosphatidyl glycerol			1	trace			
Lysophosphatidyl ethanolamine			1	1	18[b]	1[b]	
Lysophosphatidyl choline	1	1	3	8	60	3	10
Lysophosphatidyl inositol				trace	28[c]		
Nonpolar lipids	717	426	70	135	34276	229	1914
Glycolipids	18	16	5	9	1038	11	162
Phospholipids	5	5	5	9	1363	27	52
Unsaponifiable lipids	86	55	8	18	2550	936	407
Total lipids	826	502	88	171	39227	1203	2535

[a]Includes 6-0-acyl monogalactosyl diglyceride.
[b]Includes phosphatidyl serine.
[c]Includes lysophosphatidyl serine.

TABLE III

Distribution of Lipids in Amylomaize, LG-11 Maize and Waxy Maize Kernels (μg Lipid/Kernel)

Lipid	Amylomaize						LG-11 maize						Waxy maize					
	Endosperm						Endosperm						Endosperm					
	Nonstarch	Starch	Germ	Pericarp	Tip cap	Total	Nonstarch	Starch	Germ	Pericarp	Tip cap	Total	Nonstarch	Starch	Germ	Pericarp	Tip cap	Total
Steryl ester	98	10	168	12	5	293	105	8	173	13	9	308	74	7	117	8	5	211
Triglyceride	1671	27	12255	23	81	14057	739	17	7806	17	40	8619	619	76	10147	19	54	10915
Diglyceride	118	7	751	6	5	887	70	6	263	3	3	345	25	8	161	3	8	205
Free fatty acid	1221	831	259	7	11	2329	286	624	64	1	12	987	913	69	73	11	18	1084
Monoglyceride	35[a]	16	63[a]	1[a]	2[a]	117[a]	15[a]	23	8[a]	trace[a]	2[a]	48	19[a]	3	38[a]	2[a]	2[a]	64[a]
Estd. steryl glycoside	28	15	96	3	2	144	14	14	15	1	2	46	25	3	124	2	3	157
Monogalactosyl diglyceride	{ 20		{ 65	{ 1	1	{ 129	{ 26	{ 23	{ 27	1	1	{ 79		{ 2	{ 55		{ 1	{ 58
Monogalactosyl monoglyceride		41			1					trace	1							
Digalactosyl diglyceride	18		48	1	1	68	25	19	92	trace	2	138		2	49		1	52
Digalactosyl monoglyceride	24	63	79	2	1	169	25	17	36	1	1	80		3	92		1	96
N-acyl phosphatidyl ethanolamine	1	—	27	1	1	30	6		23	1	1	31	2	—	36	1		39
N-acyl lysophosphatidyl ethanolamine	{ 3	—			{ trace	{ 3	{ 1		{ 4	{ trace		{ 5	{ 2	—	{ 9	{ trace		{ 11
Diphosphatidyl glycerol		—												—				
Phosphatidyl glycerol	11	—	7	{ 1	1	20	1		8			9	1	—	8	trace	trace	9
Phosphatidyl ethanolamine	15	—	65		1	81	2		41		1	44	2	—	15	trace	trace	17
Phosphatidyl choline	58	—	140	1	2	201	7		158	1	1	167	3	—	178	1	trace	182
Phosphatidyl inositol	17	—	86	1	1	105	6		52		1	59		—	122		1	123
Phosphatidic acid	22	—	124	1	1	148	2		16	trace	1	19	1	—	18	1	1	21
Lysophosphatidyl glycerol		7				7		9		{ trace		9		2				2
Lysophosphatidyl ethanolamine	7[b]	31	4[b]	*trace*[b]	*trace*[b]	42[b]	2[b]	35			trace[b]	37[b]		2	6[b]	trace[b]		8[b]
Lysophosphatidyl choline	54	308	3	1	1	367	36	472	5	trace	1	514	1	7	18	trace		26
Lysophosphatidyl inositol[c]		7			1	8		17			1	18			9			9
Nonpolar lipids	3143	891	13496	49	104	17683	1215	678	8314	34	66	10307	1650	163	10536	43	87	12479
Glycolipids	90	119	288	7	6	510	90	73	170	3	7	343	25	10	320	2	6	363
Phospholipids	188	353	456	6	9	1012	63	533	307	2	7	912	12	11	419	3	2	447
Unsaponifiable lipids	88	54	3393	421	65	4021	155	—	405	48	10	618	198	19	784	175	22	1198
Total lipids	3509	1417	17633	483	184	23226	1523	1284	9196	87	90	12180	1885	203	12059	223	117	14487

[a]Includes 6-0-acyl monogalactosyl diglyceride.

[b]Includes phosphatidyl serine.

[c]Includes lysophosphatidyl serine.

phatic alcohols. The acyl lipids were fairly constant in composition, consisting of triglycerides, steryl esters, free fatty acids and diglycerides. The small amounts of acyl lipids in the senesced pericarp appear to be residues of lipids from early stages of kernel development.

The tip cap lipids contained substantial proportions of nonpolar lipids and unsaponifiable matter (approximately equal amounts of sterols and aliphatic alcohols), together with glycolipids and phospholipids. The tip cap lipids thus resemble pericarp lipids in some respects, while having some of the features of viable tissue such as germ and aleurone.

Whole Kernel Lipids

The contribution of lipids in each part of the kernel to the whole kernel lipids is shown in Table III. The whole kernel lipids consisted of 76-85% nonpolar lipids, 2-3% glycolipids, and 4-9% phospholipids, and their compositions fall within the ranges reported by Weber (23).

Apart from free fatty acids and monoglycerides which are in endosperm, the various lipid classes are mostly in the germ, and the whole kernel lipids are therefore similar to the germ lipids. In this respect maize is entirely different from wheat (22) and probably also most other cereals except sorghum and millet.

Fatty Acids in Lipids

The fatty acid compositions of most lipids were determined in the course of the work, but are not included in this paper (details can be had on application to the authors). For most purposes the data in Table I provide sufficient information, and they show that all three types of maize had fatty acid compositions within the normal ranges (1,6). Germ lipids (and whole kernel lipids) contained significantly more linoleate than other parts of the kernel.

DISCUSSION

To the best of our knowledge, the quantitative distribution of all the major acyl lipids throughout a cereal grain has not been described before. The results presented in this paper are consistent with previous analyses of total lipids and fatty acids (2–10) and with what is known about the composition of lipids in the basic structural parts of cereal grains (1).

Our data for lipid classes in the whole kernels of LG-11 (Table III) agree well with Weber's analyses of hybrid 51 at maturity (23,24). However, Weber's data did not reveal the low levels of lipid in endosperm nonstarch fraction and in pericarp, nor the fact that they contained so little polar lipids.

We believe that the lipids in these tissues are remnants of greater quantities of lipids which functioned during kernel development and were then largely degraded during pericarp senescence and the drying out of the endosperm. In a subsequent study of lipids in developing maize kernels, we obtained data which support this view, and we will publish the results in due course.

In contrast to the above remarks, we consider that free fatty acids and lysophospholipids in maize starches are normal monoacyl lipid components of these starches which may occur as amylose inclusion complexes within the granules, as appears to be the case in other cereals.

ACKNOWLDGMENT

A.D. Evers, Flour Milling and Baking Research Association, Chorleywood, England provided and interpreted scanning electron micrographs of aleurone cells layers.

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[Received August 16, 1978]