Lipid Classes and Their Fatty Acids at Different Loci of Albacore (*Thunnus alalunga*): Effects of Precooking

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A zonal lipid study of albacore before and after the cooking process was carried out. Lipid classes as well as their corresponding fatty acids were identified and quantified. Triglycerides (TG) were found to be the major components (78–92%), followed by phosphatidylcholine (1–4%) and free fatty acids (2–7%). Due to cooking, a slight loss in TG was obtained, accompanied by variable increases in all the other lipid classes. The fatty acid qualitative composition was very similar in all the lipid classes, although big differences from a quantitative point of view were obtained. A very high level of polyunsaturated fatty acids was found in phosphatidylcholine (40–47%) while this was very low in free fatty acids (16–26%). During cooking no significant changes in the fatty acid composition of lipid classes were obtained.

Many of the problems with canned fish can be related to the quality of raw material, which is continuously changing during the storage period. Generally, albacore is frozen for later processing in canneries, but frozen storage often leads to dehydration and rancidity, and thawing can produce detrimental effects.

In fish canning, precooking is a very important step required to reduce water content (Joshi and Saralaya, 1982), but the effects on lipids are not well-known and different fishes can react in different ways, depending on their chemical composition.

Considerable variation exists in the fat content among different individuals and also at different loci within each fish (Dotson, 1978), but no information is available on its lipid classes composition.

Many works (Maclean and Castell, 1964; Castell et al., 1966; Dyer and Morton, 1956; Dyer and Fraser, 1959) have studied lipid changes in fish muscle during storage at low temperatures. However, these studies have been mainly restricted to the changes in lipid content and in total fatty acid composition; no information is available on the lipid composition of this species and on the effect of steam cooking on lipid classes and their fatty acids.

On the other hand, recent works point out the important role of fish lipids in diets recommended for persons with cardiovascular diseases (Hearn et al., 1987) and tumorigenesis (Carroll and Braden, 1986). For this reason it would be interesting to evaluate the cooking process on the quality and nutritional benefits of the marine products. Albacore was chosen for the present work because of its importance to commerical fisheries in Spain as well as its great significance in the canning industry.

Thus, this work was designed to study the lipid composition at different loci and to investigate the effect of steam cooking on lipids from the point of view of changes in lipid classes of albacore.

MATERIALS AND METHODS

Raw Material and Processing. Albacore (*Thunnus alalunga*) used in this work was caught by a commercial tuna vessel round the point 43° N and 27° W during June 1985. The fish was kept in boxes and transported on ice during 10 days. After arrival to our laboratory the fish were frozen at −40 °C and stored at −18 °C for 6 months.

Six individuals were employed, and three zones of each, known in the commercial literature as back muscle (BM), ventral muscle (VM), the belly flap muscle (BFM), were used in this experiment.

The fish was processed in our pilot plant according to the following procedure: Whole eviscerated and beheaded fish was cooked (at 102–103 °C) with steam until a final backbone temperature of 65 °C (90 min); then, it was cooled at room temperature (14 °C) for about 5 h, before sampling.

Lipid Extraction and Determination. Lipids were extracted from the samples by the Bligh and Dyer method (1959). An aliquot of the extract was dried to constant weight by a nitrogen flow in order to obtain the lipid content.

Separation of Lipid Classes by Column and Thin-Layer Chromatography. The total lipids were fractionated into lipid classes on a silicic acid column. The silicic acid (E. Merck, 70–230 mesh) was washed with water and methanol to remove fines and impurities. It was activated at 120 °C overnight. A slurry of 50 g of silicic acid in hexane was poured into the column.

A 700-mg portion of total lipids was dissolved in hexane and quantitatively transferred to the column. The solvent system polarities employed for separation into the column are shown in Table I. The fractions obtained were evaporated in a rotary vacuum evaporator and stored in chloroform solution under N_2 atmosphere. The purity of the lipid classes was checked by TLC on 20 × 20 cm plates coated with a layer (0.5 mm) of silica gel G (E. Merck).

The lipid classes were identified by comparison with standard references and by using general and specific reagents (Lepage, 1964).

Lipid Class Determination. The content of free fatty acids (FFA) was determined by the Lowry and Tinsley method (1976), based on a complex formation with AcOCu–pyridine. Sterols and sterol esters were determined by the method of Huang et al. (1961), based on the Liebermann–Buchardt reaction. Each of the phospholipid classes was determined by the method of Raheja et al. (1973), based on a complex formation with ammonium molybdate.

The remaining lipid classes, having an ester linkage, were determined by the method of Vioque and Holman (1962), based

Table I. Solvent Systems Employed as Eluents in the Column Chromatography Separation of Lipid Classes[a]

solvent system	vol, mL	eluted lipid class
hexane	50	
5% ether/hexane	200	W, SE
7% ether/hexane	100	ME
15% ether/hexane	400	TG
75% ether/hexane	300	DG, FS, FFA
ether	200	MG
methanol	300	PE, PC, PS, LPC

[a] Abbreviations: W, waxes; SE, sterol esters; ME, methylic esters; TG, triglycerides; FFA, free fatty acids; DG, diglycerides; FS, free sterols; MG, monoglycerides; PE, phosphatidylethanolamine; PC, phosphatidylcholine; PS, phosphatidylserine; LPC, lysophosphatidylcholine.

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Table II. Total Lipid (TL) Content (g/100 g of Muscle) and Percentage of Lipid Classes[a] in TL of the Three Studied Zones in the Raw and Cooked Samples[b]

	back muscle		ventral muscle		belly flap muscle	
	raw	cooked	raw	cooked	raw	cooked
TL	5.82 ± 0.15	4.92 ± 0.11	4.32 ± 0.13	3.88 ± 0.10	18.54 ± 0.92	13.99 ± 0.58
W	0.09 ± 0.04	0.10 ± 0.02	0.10 ± 0.05	0.10 ± 0.04	0.05 ± 0.01	0.06 ± 0.02
SE	0.06 ± 0.04	0.08 ± 0.02	0.08 ± 0.05	0.08 ± 0.04	0.04 ± 0.01	0.04 ± 0.02
ME	0.06 ± 0.02	0.28 ± 0.08	0.29 ± 0.11	0.38 ± 0.08	0.05 ± 0.01	0.06 ± 0.01
TG	83.69 ± 1.20	81.42 ± 1.27	80.12 ± 1.08	78.72 ± 1.12	92.04 ± 1.07	88.52 ± 0.96
FFA	5.30 ± 0.42	6.18 ± 0.53	7.00 ± 0.61	7.39 ± 0.54	2.41 ± 0.26	3.73 ± 0.34
DG	1.25 ± 0.21	1.48 ± 0.22	1.18 ± 0.14	1.30 ± 0.14	1.43 ± 0.15	1.93 ± 0.17
FS	1.07 ± 0.18	1.22 ± 0.17	1.19 ± 0.12	1.27 ± 0.14	0.49 ± 0.11	0.55 ± 0.10
MG	0.47 ± 0.10	0.51 ± 0.12	0.47 ± 0.08	0.47 ± 0.09	0.22 ± 0.08	0.16 ± 0.09
PE	0.61 ± 0.11	0.98 ± 0.21	1.21 ± 0.17	1.32 ± 0.14	0.31 ± 0.07	0.39 ± 0.09
PC	3.91 ± 0.40	4.18 ± 0.37	4.06 ± 0.28	4.38 ± 0.30	0.98 ± 0.12	1.08 ± 0.13
PS	0.36 ± 0.08	0.53 ± 0.11	0.91 ± 0.11	1.00 ± 0.12	0.22 ± 0.09	0.26 ± 0.10
LPC	0.73 ± 0.12	1.13 ± 0.01	1.50 ± 0.15	1.75 ± 0.22	0.32 ± 0.08	0.54 ± 0.12

[a] Abbreviations as specified in Table I. [b] Mean of three determinations ± standard deviation.

on the methylic ester conversion into hydroxamic acids and further complexion with Fe(III).

Transesterification of Lipid Classes and Determination of Their Fatty Acids. Lipid classes were transesterified with BF_3–MeOH complex, in accord to Morrison and Smith (1964).

Fatty acid methyl esters were analyzed with a Varian Vista 6000 gas chromatograph equipped with a 30-m flexible capillary column SP-2330 (Supelco). An isothermal separation at 190 °C with injector temperature, 220 °C and detector temperature 230 °C was carried out. Carrier gas used was N_2 flowing with a linear velocity of 18 cm/s. The individual fatty acid methyl esters were identified by comparison of the retention times to those of standard methylic ester mixtures including PUFA No. 1, marine source (Supelco), and by semilogarithme plots of retention times against carbon chain lengths (Ackman, 1969).

RESULTS AND DISCUSSION

Data presented herein do not represent all albacore tuna as it was caught (Material and Methods) at one time and one place but was useful enough for the mentioned purposes.

Table II shows the weight percentage of total lipids (TL) in the muscle as well as the content of each lipid class in albacore fat for the different zones. The high level of fat (18.54%) in the belly flap (BFM) muscle indicated that this zone is a notoriously fat section of the albacore, which may be employed as endogenous energy (Ackman and Eaton, 1971). This role would be accomplished by the triglyceride class (92%), in spite of other neutral lipid classes like waxes and sterol esters used by other marine animals (Kaitaranta and Ackman, 1981).

The data showed that phosphatidylcholine (PC) was the main phospholipid class and was also the third major component of all lipid classes. PC content was high in the back muscle (BM) and ventral muscle (VM) and low in the BFM, according to Weihrauch and Son (1983), who reported that the phospholipid concentration decreases when the content of total lipid in fatty fish increases. Other minor constituent phospholipids were phosphatidylserine, phosphatidylethanolamine, and lysophosphatidylcholine.

Due to cooking, a general decrease in total lipid content in each of the studied zones was obtained. Differences were very significant in the BFM. In lipid classes a significant decrease in TG was obtained in the case of the BFM. All other lipid classes suffered an increase, which was significative in DG, FFA, and LPC also in the BFM.

Table III shows lipid class relationships that may have varied during cooking due to hydrolysis of the bigger molecules. The data show that the TG/DG relation decreased more as the zone was exposed to steam during cooking, especially in the BFM. This is in accord with diglyceride production.

Table III. Lipid Class[a] Relations (TG/DG, DG/MG, PC/LPC) Affected by Hydrolysis during Cooking in the Three Studied Zones[b]

	raw	cooked
	Back Muscle	
TG/DG	66.95 ± 1.31	55.01 ± 1.22
DG/MG	2.66 ± 0.23	2.90 ± 0.35
PC/LPC	5.36 ± 0.48	3.70 ± 0.42
	Ventral Muscle	
TG/DG	67.90 ± 1.12	60.55 ± 1.13
DG/MG	2.51 ± 0.37	2.77 ± 0.34
PC/LPC	2.71 ± 0.30	2.50 ± 0.30
	Belly Flap Muscle	
TG/DG	64.36 ± 1.10	45.87 ± 1.06
DG/MG	6.50 ± 0.52	12.06 ± 0.98
PC/LPC	3.06 ± 0.38	2.00 ± 0.19

[a] Abbreviations as specified in Table I. [b] Mean of three determinations ± standard deviation.

No significant changes were obtained for the DG/MG relation in BM and VM zones; however, a significant increase was found in BFM zone.

From the PC/LPC relation, cooking led to a shift to LPC formation in all the zones, this being significant in the BM and BFM zones.

It can be concluded that hydrolytic effects of the cooking leads to formation of diglycerides and lysophosphatidylcholine, but not monoglycerides.

The fatty acids of lipid classes for each of the studied zones considered before and after cooking are shown in Tables IV–IX. Qualitatively, all lipid components had identical fatty acid compositions but with quantitative variations.

The highest proportion (40.4–47.4%) of polyunsaturated fatty acids was found in phosphatidylcholine, whereas the lowest (17.9–26.1%) was in FFA. Among the polyunsaturated fatty acids, the highest proportion was of the 22:6, especially in the PC class. However, the proportion of this fatty acid was lower in FFA. On the other hand, a high content in saturated fatty acids (16:0 and 18:0) was obtained in FFA.

Due to cooking, a decrease in saturated and monounsaturated fatty acids and an increase in polyunsaturated fatty acids were observed in diglycerides of the BM and the VM zones. In the BFM, the opposite variations were obtained. Similar variations were also found in the FFA, but the only significant differences were obtained in the BFM.

The reason for this distribution may be the deeper exposure to steam of the BFM with respect to the two other

Table IV. Fatty Acid (FA) Content (%) in Lipid Classes[a] in the Raw Back Muscle[b]

TG	FFA	FA	DG	PC
3.7 ± 0.3	3.0 ± 0.3	14:0	3.8 ± 0.2	0.9 ± 0.2
1.3 ± 0.4	2.2 ± 0.3	15:0	1.5 ± 0.1	3.4 ± 0.3
19.3 ± 0.7	33.0 ± 0.9	16:0	16.6 ± 0.6	17.7 ± 0.6
2.4 ± 0.3	2.5 ± 0.2	17:0	2.8 ± 0.1	1.2 ± 0.2
6.6 ± 0.4	11.0 ± 0.3	18:0	5.4 ± 0.3	6.2 ± 0.4
33.3 ± 1.4	51.7 ± 1.7	total satd	30.1 ± 1.1	29.4 ± 1.3
6.0 ± 0.3	4.4 ± 0.2	16:1	6.8 ± 0.4	1.6 ± 0.3
0.8 ± 0.2	0.9 ± 0.2	17:1	1.0 ± 0.2	0.9 ± 0.3
20.9 ± 0.6	18.1 ± 0.6	18:1	22.3 ± 0.7	12.5 ± 0.5
3.6 ± 0.3	2.0 ± 0.2	22:1	3.3 ± 0.3	4.8 ± 0.2
1.2 ± 0.3	0.4 ± 0.1	24:1	2.1 ± 0.2	0.9 ± 0.1
32.5 ± 1.3	25.8 ± 1.1	total monounsatd	35.5 ± 1.3	20.7 ± 1.2
2.2 ± 0.2	2.2 ± 0.3	18:2	2.5 ± 0.3	1.1 ± 0.1
3.9 ± 0.4	2.3 ± 0.2	18:3	3.7 ± 0.4	1.0 ± 0.2
1.1 ± 0.1	0.6 ± 0.1	18:4	1.4 ± 0.1	0.3 ± 0.1
1.5 ± 0.1	1.0 ± 0.1	20:4	1.1 ± 0.1	1.4 ± 0.2
5.0 ± 0.2	2.9 ± 0.3	20:5	4.5 ± 0.5	5.1 ± 0.2
0.7 ± 0.2	0.6 ± 0.1	22:4	0.7 ± 0.1	1.5 ± 0.2
1.5 ± 0.3	0.3 ± 0.1	22:5	1.2 ± 0.2	1.0 ± 0.1
15.5 ± 0.6	8.0 ± 0.5	22:6	16.0 ± 0.7	36.0 ± 0.9
31.4 ± 1.5	17.9 ± 1.3	total polyunsatd	31.1 ± 1.6	47.4 ± 1.5

[a] Abbreviations as specified in Table I. [b] Mean of three determinations ± standard deviation.

Table V. Fatty Acid (FA) Content (%) in Lipid Classes[a] in the Cooked Back Muscle[b]

TG	FFA	FA	DG	PC
3.9 ± 0.2	2.3 ± 0.3	14:0	3.3 ± 0.3	1.1 ± 0.3
1.4 ± 0.4	1.6 ± 0.2	15:0	1.2 ± 0.2	4.3 ± 0.3
19.5 ± 0.8	33.2 ± 0.8	16:0	12.6 ± 0.4	16.5 ± 0.5
2.4 ± 0.4	1.9 ± 0.3	17:0	1.6 ± 0.1	1.5 ± 0.2
6.0 ± 0.4	11.5 ± 0.3	18:0	4.3 ± 0.2	5.6 ± 0.2
33.2 ± 1.6	50.5 ± 1.4	total satd	23.0 ± 1.1	29.0 ± 1.2
5.9 ± 0.3	4.5 ± 0.2	16:1	7.6 ± 0.4	1.5 ± 0.2
0.8 ± 0.4	0.8 ± 0.3	17:1	0.9 ± 0.2	0.7 ± 0.3
20.4 ± 0.7	17.7 ± 0.7	18:1	19.3 ± 0.6	12.6 ± 0.5
3.2 ± 0.4	2.2 ± 0.3	22:1	3.2 ± 0.3	5.3 ± 0.2
1.3 ± 0.3	0.5 ± 0.1	24:1	0.9 ± 0.3	0.9 ± 0.2
31.6 ± 1.5	25.7 ± 1.3	total unsatd	31.9 ± 1.3	21.0 ± 1.2
2.1 ± 0.2	2.1 ± 0.3	18:2	2.2 ± 0.3	1.0 ± 0.2
3.6 ± 0.5	2.3 ± 0.3	18:3	3.2 ± 0.3	0.9 ± 0.3
1.2 ± 0.2	0.5 ± 0.2	18:4	1.3 ± 0.1	0.3 ± 0.1
1.5 ± 0.3	1.0 ± 0.1	20:4	1.2 ± 0.1	1.1 ± 0.1
5.1 ± 0.4	3.6 ± 0.2	20:5	5.8 ± 0.2	4.9 ± 0.2
0.6 ± 0.2	0.5 ± 0.1	22:4	0.8 ± 0.2	2.7 ± 0.3
1.5 ± 0.3	0.5 ± 0.2	22:5	1.6 ± 0.3	0.9 ± 0.1
15.7 ± 0.6	9.8 ± 0.6	22:6	25.2 ± 0.7	34.8 ± 0.8
31.3 ± 1.6	20.3 ± 1.4	total polyunsatd	41.3 ± 1.5	46.6 ± 1.5

[a] Abbreviations as specified in Table I. [b] Mean of three determinations ± standard deviation.

Table VI. Fatty Acid (FA) Content (%) in Lipid Classes[a] in the Raw Ventral Muscle[b]

TG	FFA	FA	DG	PC
4.2 ± 0.4	2.7 ± 0.1	14:0	4.3 ± 0.2	0.5 ± 0.1
1.6 ± 0.5	1.9 ± 0.1	15:0	1.5 ± 0.1	6.6 ± 0.3
19.5 ± 0.7	33.0 ± 0.7	16:0	19.3 ± 0.5	14.8 ± 0.5
2.2 ± 0.2	2.2 ± 0.3	17:0	2.0 ± 0.1	0.5 ± 0.2
6.0 ± 0.3	13.0 ± 0.5	18:0	5.9 ± 0.2	10.5 ± 0.4
33.5 ± 1.4	52.8 ± 1.3	total satd	33.0 ± 1.0	32.9 ± 1.2
6.2 ± 0.4	4.6 ± 0.3	16:1	6.5 ± 0.1	3.5 ± 0.2
1.0 ± 0.2	0.8 ± 0.2	17:1	1.0 ± 0.1	0.7 ± 0.1
20.2 ± 0.7	17.9 ± 0.4	18:1	20.1 ± 0.7	15.7 ± 0.7
3.1 ± 0.1	1.9 ± 0.2	22:1	3.2 ± 0.2	4.6 ± 0.2
1.2 ± 0.1	0.5 ± 0.1	24:1	1.3 ± 0.3	0.4 ± 0.1
31.7 ± 1.2	25.7 ± 1.1	total monounsatd	32.1 ± 1.2	24.9 ± 1.3
2.2 ± 0.1	2.0 ± 0.1	18:2	2.2 ± 0.1	1.8 ± 0.3
3.5 ± 0.2	2.1 ± 0.3	18:3	3.9 ± 0.2	0.9 ± 0.1
1.2 ± 0.2	0.5 ± 0.2	18:4	1.2 ± 0.1	0.3 ± 0.1
1.9 ± 0.3	0.8 ± 0.2	20:4	2.1 ± 0.1	0.7 ± 0.3
4.8 ± 0.3	3.2 ± 0.2	20:5	5.1 ± 0.2	4.2 ± 0.5
0.6 ± 0.1	0.5 ± 0.2	22:4	0.6 ± 0.1	1.2 ± 0.1
1.4 ± 0.2	0.4 ± 0.1	22:5	1.3 ± 0.1	0.7 ± 0.1
15.8 ± 0.6	9.2 ± 0.5	22:6	15.0 ± 0.6	30.6 ± 0.8
31.4 ± 1.4	18.7 ± 1.3	total polyunsatd	31.4 ± 1.2	40.4 ± 1.6

[a] Abbreviations as specified in Table I. [b] Mean of three determinations ± standard deviation.

Table VII. Fatty Acid (FA) Content (%) of Lipid Classes[a] in the Cooked Ventral Muscle[b]

TG	FFA	FA	DG	PC
4.1 ± 0.2	2.2 ± 0.1	14:0	5.3 ± 0.3	1.1 ± 0.1
1.4 ± 0.1	1.6 ± 0.1	15:0	2.3 ± 0.3	7.2 ± 0.3
20.2 ± 0.8	32.6 ± 0.7	16:0	12.7 ± 0.5	14.6 ± 0.7
1.8 ± 0.1	2.2 ± 0.2	17:0	2.4 ± 0.1	0.4 ± 0.2
6.1 ± 0.3	11.6 ± 0.3	18:0	5.3 ± 0.2	11.3 ± 0.3
33.6 ± 1.2	50.2 ± 1.2	total satd	28.0 ± 1.2	34.6 ± 1.3
5.5 ± 1.4	4.3 ± 0.2	16:1	7.2 ± 0.2	3.7 ± 0.5
0.7 ± 0.2	0.8 ± 0.3	17:1	1.5 ± 0.1	0.8 ± 0.2
19.9 ± 0.7	17.4 ± 0.7	18:1	19.7 ± 0.6	15.2 ± 0.5
3.5 ± 0.2	2.1 ± 0.3	22:1	2.6 ± 0.2	4.3 ± 0.2
1.4 ± 0.2	0.5 ± 0.1	24:1	0.8 ± 0.2	0.5 ± 0.1
31.0 ± 1.3	25.1 ± 1.3	total monounsatd	31.8 ± 1.1	24.5 ± 1.2
2.2 ± 0.1	2.1 ± 0.2	18:2	2.5 ± 0.2	1.6 ± 0.3
3.5 ± 0.4	2.2 ± 0.1	18:3	2.9 ± 0.3	1.0 ± 0.2
1.2 ± 0.2	0.6 ± 0.2	18:4	0.7 ± 0.1	0.4 ± 0.1
1.6 ± 0.1	0.9 ± 0.1	20:4	1.2 ± 0.1	0.5 ± 0.1
4.8 ± 0.2	3.5 ± 0.2	20:5	5.1 ± 0.3	4.2 ± 0.3
0.6 ± 0.2	0.5 ± 0.1	22:4	0.8 ± 0.1	1.2 ± 0.2
1.4 ± 0.3	0.5 ± 0.1	22:5	1.4 ± 0.2	0.8 ± 0.2
16.0 ± 0.7	10.3 ± 0.6	22:6	21.4 ± 0.8	28.6 ± 0.5
31.3 ± 1.5	20.6 ± 1.3	total polyunsatd	36.0 ± 1.5	38.3 ± 1.4

[a] Abbrevations as specified in Table I. [b] Mean of three determinations ± standard deviation.

Table VIII. Fatty Acid (FA) Content (%) of Lipid Classes[a] in the Raw Belly Flap Muscle[b]

TG	FFA	FA	DG	PC
4.2 ± 0.3	3.0 ± 0.2	14:0	3.8 ± 0.3	1.3 ± 0.3
1.4 ± 0.2	1.4 ± 0.2	15:0	1.4 ± 0.3	2.7 ± 0.3
20.9 ± 0.7	28.6 ± 0.7	16:0	15.2 ± 0.5	23.2 ± 0.5
2.1 ± 0.3	2.0 ± 0.3	17:0	2.0 ± 0.2	1.5 ± 0.2
5.8 ± 0.4	6.9 ± 0.3	18:0	4.6 ± 0.2	4.9 ± 0.2
34.4 ± 1.4	41.9 ± 1.3	total satd.	27.0 ± 1.2	33.6 ± 1.3
6.6 ± 0.5	6.4 ± 0.5	16:1	7.8 ± 0.5	1.9 ± 0.2
1.0 ± 0.2	0.7 ± 0.2	17:1	0.8 ± 0.1	0.6 ± 0.2
19.0 ± 0.7	19.0 ± 0.7	18:1	19.2 ± 0.6	10.6 ± 0.6
3.2 ± 0.4	2.5 ± 0.1	22:1	3.2 ± 0.2	3.9 ± 0.5
1.2 ± 0.3	0.8 ± 0.1	24:1	1.4 ± 0.2	1.3 ± 0.1
31.0 ± 1.4	29.4 ± 1.3	total monounsatd	32.4 ± 1.3	18.3 ± 1.3
2.0 ± 0.3	2.9 ± 0.4	18:2	2.1 ± 0.1	1.5 ± 0.1
3.8 ± 0.4	2.3 ± 0.4	18:3	3.3 ± 0.2	1.2 ± 0.1
1.2 ± 0.1	0.9 ± 0.1	18:4	1.4 ± 0.1	0.6 ± 0.2
1.4 ± 0.1	1.6 ± 0.3	20:4	1.7 ± 0.3	1.3 ± 0.2
5.7 ± 0.6	7.1 ± 0.5	20:5	6.3 ± 0.5	5.0 ± 0.4
0.6 ± 0.1	0.6 ± 0.2	22:4	0.8 ± 0.1	1.4 ± 0.2
1.3 ± 0.2	1.1 ± 0.1	22:5	1.3 ± 0.1	1.1 ± 0.1
15.2 ± 0.7	9.6 ± 0.6	22:6	20.2 ± 0.7	30.7 ± 0.8
31.2 ± 1.6	26.1 ± 1.7	total polyunsatd	37.1 ± 1.4	42.8 ± 1.4

[a] Abbreviations as specified in Table I. [b] Mean of three determinations ± standard deviation.

Table IX. Fatty Acid (FA) Content (%) of Lipid Classes[a] in the Cooked Belly Flap Muscle[b]

TG	FFA	FA	DG	PC
4.2 ± 0.3	4.2 ± 0.3	14:0	4.1 ± 0.5	1.8 ± 0.2
1.8 ± 0.3	1.7 ± 0.2	15:0	1.5 ± 0.1	1.8 ± 0.3
19.6 ± 0.7	35.0 ± 0.9	16:0	16.1 ± 0.7	16.3 ± 0.7
2.3 ± 0.2	2.5 ± 0.4	17:0	2.1 ± 0.1	1.5 ± 0.5
6.0 ± 0.4	7.1 ± 0.4	18:0	5.2 ± 0.3	7.1 ± 0.7
33.9 ± 1.4	50.5 ± 1.6	total satd	29.0 ± 1.2	28.5 ± 1.5
6.3 ± 0.4	7.5 ± 0.6	16:1	8.4 ± 0.5	1.8 ± 0.3
0.8 ± 0.2	0.8 ± 0.2	17:1	0.9 ± 0.3	0.9 ± 0.2
19.5 ± 0.6	18.6 ± 0.7	18:1	22.3 ± 0.7	9.0 ± 0.7
3.4 ± 0.4	1.8 ± 0.3	22:1	3.3 ± 0.5	5.0 ± 0.6
1.3 ± 0.2	0.4 ± 0.2	24:1	1.4 ± 0.2	1.4 ± 0.3
31.3 ± 1.4	29.1 ± 1.4	total monounsatd	36.3 ± 1.5	18.1 ± 1.6
2.2 ± 0.4	3.0 ± 0.4	18:2	2.2 ± 0.2	1.6 ± 0.2
3.4 ± 0.3	1.7 ± 0.2	18:3	5.4 ± 0.4	1.0 ± 0.2
1.2 ± 0.1	0.7 ± 0.2	18:4	2.0 ± 0.4	0.7 ± 0.2
1.3 ± 0.1	1.0 ± 0.2	20:4	1.1 ± 0.1	1.8 ± 0.1
5.3 ± 0.4	3.3 ± 0.3	20:5	3.9 ± 0.5	5.1 ± 0.4
0.6 ± 0.3	0.4 ± 0.2	22:4	0.6 ± 0.1	1.6 ± 0.4
1.4 ± 0.3	0.5 ± 0.1	22:5	1.4 ± 0.1	1.1 ± 0.2
15.9 ± 0.7	5.9 ± 0.7	22:6	13.2 ± 0.8	35.4 ± 0.7
31.3 ± 1.7	16.5 ± 1.5	total polyunsatd	29.8 ± 1.7	48.3 ± 1.6

[a] Abbreviations as specified in Table I. [b] Mean of three determinations ± standard deviation.

zones during cooking.

In the case of triglycerides, no significant variations have been found. For phosphatidylcholine, it is interesting to point out the changes in the BFM, such as the decrease of saturated fatty acids, and the increase of the polyunsaturated fatty acids.

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Effects of Cultivar and Soil pH on Abrasive Milling Rate and Composition of Sorghum Grain

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Four cultivars of grain sorghum, Warner W-840DR, Dekalb C42y+, Funk G-552DR, and NK Savannah 5, which had been grown on acid (pH <4.9) and neutral (pH >6.0) pH soils were studied. Samples weighing 4.5 kg were abrasively milled for short, successive intervals until a cumulative extraction rate (yield of milled grain) of ~50% was reached for each sample. Third-degree polynomials provided an excellent description of the milling process for each cultivar. Milling rates (the rates at which the outer layers of the grain were removed) followed the order Dekalb > Warner > Funk > Savannah. Soil pH affected milling rate for Dekalb and Savannah. For all cultivars, the relative amount of starch in milled grain increased as the outer layers were removed. For all cultivars, the relative contents of protein, fat, fiber, and ash and of tannin for Savannah were reduced in the milled grain as milling proceeded. Soil pH affected starch and ash content in a complex, cultivar-dependent manner.

Grain sorghum (*Sorghum bicolor* (L.) Moench), one of the world's leading cereal crops, fills an important niche due to its drought tolerance (Pedersen and Eggum, 1983). This characteristic has caused expanded sorghum production in semiarid tropical and subtropical regions of the world. Unfortunately, infertility due to acid soil stress often limits yields in these areas. In Georgia where several recent growing seasons have been below average in rainfall, sorghum production increased from 4.7 megabushels in 1970–1972 to 12.1 megabushels in 1980–1982. Supporting this increase in production has been an extensive breeding effort to develop cultivars tolerant to the acidic soils found in the state (Duncan, 1981a,b, 1984; Duncan et al., 1984)).

Although sorghum grain is almost exclusively utilized for animal feed in the United States, there has been considerable research in this country and elsewhere on the factors controlling its functional, nutritional, and toxicological properties as they relate to human food applications (Morad et al., 1984; Choto et al., 1985; Capampang et al., 1984; Chavan et al., 1979). Most of the world sorghum crop

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