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Characterization of quinoa (*Chenopodium quinoa*) lipids

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Lipids isolated from quinoa seed and seed fractions were characterized for lipid classes and their fatty acid composition. Quinoa seed lipids contained the largest amount of neutral lipids among all the seed fractions analyzed. A very high content of free fatty acids was detected in whole quinoa seed and hulls, accounting for 18·9 and 15·4% of total lipids, respectively. Triglycerides were the major fraction present and accounted for over 50% of the neutral lipids. Diglycerides were present in whole seed and contributed 20% of the neutral lipid fraction. Of the phospholipids examined, lysophosphatidyl ethanolamine, was the most abundant and made up 45% of the total polar lipids. Phosphatidyl choline was the second largest phospholipid component and contributed 12% of whole seed phospholipids. Considerable variation in phospholipids was evident between the different fractions. The overall fatty acid composition of whole quinoa seeds, however, was similar to that reported for other cereal grains, with linoleic, oleic and palmitic acids as the major acids present.

INTRODUCTION

Quinoa (*Chenopodium quinoa*), a native grain crop, has been cultivated for centuries in the highlands of South America. It is an annual broad-leafed herb with white or pink seeds that grow in large sorghum-like clusters (Theurer Wood, 1985). The seeds of quinoa are one of the richest sources of protein among grain crops, ranging over 12–19% (Risic & Galwey, 1984; Gross *et al.*, 1989; Chauhan *et al.*, 1992). The protein quality in cooked and leached quinoa seeds has been reported to be equivalent to that in milk (Gross *et al.*, 1989). Interest in quinoa as a valuable food source has been renewed on our continent in recent years due to its versatility and low growth requirements, including low rainfall, high altitudes, thin cold air, hot sun, sub-freezing temperatures as well as poor sandy alkaline soils (Risic & Galwey, 1984). One of the major shortcomings is the presence of saponin components in the pericarp of quinoa seeds which contribute to both bitterness as well as detergent action in water (Reichert *et al.*, 1986). Analyses of quinoa seed for content of major components including proteins, sugars, minerals, vitamins, amino acids, fat and main fatty acids composition were reported previously (Atwell *et al.*, 1983; Gross *et al.*, 1989; Chauhan *et al.*, 1992; Ruales & Nair, 1993). Little information is available, however, on the lipids in quinoa seeds. This study reports a detailed analysis of the lipids composition in quinoa seed fractions.

MATERIALS AND METHODS

Materials

Quinoa seeds (*Chenopodium quinoa* Willd.) grown in Rossburn, Manitoba were provided by Mr H. Hrubniek. The seeds were cleaned, milled and separated into fractions including hulls, bran and flour as described previously (Chauhan *et al.* 1992).

Methods

Proximate analyses of quinoa seeds were performed according to AACC methods (1988), including moisture (AACC method 44-15A), crude protein (AACC method 46-10), crude fat (AACC method 30-20) and crude fiber (AACC method 32-10) (Chauhan *et al.*, 1992).

Lipids extraction

Three separate portions of quinoa seeds and seed fractions were each analyzed twice for lipids composition. Quinoa seed and seed fractions were ground and passed through a 750 μm mesh sieve and then lipid was extracted with a hot *n*-butanol saturated with water in a ratio of 17 ml solvent to 1 g of extracted seed material (Morrison *et al.*, 1980). Three 2 h extractions were performed on all quinoa seed fractions in round-bottom screw-cap tubes (50 ml) in a boiling water bath. After

each extraction, samples were cooled with cold water and the solvent decanted by centrifugation. Two additional extractions with chloroform–methanol–water (1:2:0·8, v/v/v) were performed. The last two extracts were combined and 20 ml each of chloroform and water added. The separated chloroform layer was combined with the butanol extract and concentrated in a tared flask using a rotary evaporator under nitrogen blanket. The weight of the flask with dried lipids was measured and the amount of lipids calculated. The dried residue was then dissolved in chloroform–isopropanol (2:1, v/v) and stored in screw-cap vials in the freezer at −30°C until characterized.

LIPIDS CHARACTERIZATION

Thin layer–flame ionization (TLC–FID)

In the case of the total lipid extracts, three consecutive solvent developments were performed to separate neutral lipids, glycolipids and phospholipids as described elsewhere (Przybylski & Eskin, 1994). Neutral lipids were separated on chromarods with a solvent mixture of dichloroethane–chloroform–acetone–acetic acid (126:21:3:0·5, v/v/v/v). Galactolipids were developed in acetone–water–acetic acid (70:1·2:1·5, v/v/v). Polar lipids were separated in a solvent mixture composed of chloroform–methanol–water–acetic acid (67:29:2·5:0·3, v/v/v/v). The amount of each lipid component was calculated using an individual calibration curve for each of the compounds analyzed (Przybylski & Eskin, 1991).

Solid phase extraction

The methods followed in this paper are those described by Przybylski and Eskin (1994). The extracted lipids were separated into classes using solid phase extraction (SPE) with aminopropyl silica (Sep-Pack NH_2). Total lipids in the amount of 10 mg were applied to the cartridge in chloroform or chloroform–isopropanol (2:1 v/v) and fractions eluted as follows: neutral lipids with 8 ml of chloroform–isopropanol (2:1 v/v), free fatty acids with 8 ml of diethyl ether with 2% (v/v) of acetic acid, and polar lipids with 8 ml of methanol.

Neutral lipid fractions were evaporated to dryness under nitrogen, washed twice with 1 ml of hexane and evaporated to dryness after each addition, then dissolved in 1–2 ml of this solvent. The hexane solution was applied to a new cartridge and separation was performed as follows: waxes with 6 ml of hexane, triglycerides (TG) with 12 ml of 5% (v/v) ethyl acetate in hexane, diglycerides (DG) with 6 ml of 15% (v/v) ethyl acetate in hexane, and monoglycerides (MG) with chloroform–methanol (2:1, v/v). All fractions were evaporated to dryness and dissolved in 0.5 ml of chloroform–methanol (2:1, v/v) and the purity of these fractions checked by thin-layer chromatography with flame ionization detector (TLC–FID) or Iatroscan. In addition to checking for purity, these fractions were analyzed for their fatty acids composition.

Gas chromatography

Fatty acids from fractions were esterified by placing 8 ml of 10% hydrochloric acid in methanol in screw-cap vials using 1–10 mg of dried lipid samples. The vials were heated at 60°C for 1 h, then cooled down and 3 ml of petroleum ether was added followed by 4 ml 20% sodium chloride solution. The extraction was repeated three times with an additional 3 ml of petroleum ether. The extracts were combined and evaporated to dryness at room temperature using a gentle stream of nitrogen to prevent oxidation (Przybylski and Eskin, 1988). The dried residue was dissolved in 100–500 μl *i*-octane and 0·5–3·0 μl injected into the gas chromatograph, depending on the concentration of the lipids. Fatty acids were separated on a Perkin-Elmer 9500 gas chromatograph with a flame ionization detector. Individual components were identified by comparison with standard mixtures of fatty acid methyl esters. The fused silica capillary column 30 m × 0·25 mm i.d. with 0·25 μm layer of DB-225 phase was used (J&W, Rancho Cordova, CA). Column temperature was programmed from 150 to 225°C at a rate of 5°C per minute. The lower temperature was held for 2 min and the upper temperature for 15 min. The injector and detector temperatures were both held at 265°C. The weight percentage was calculated by applying multiplication factors derived from calibration of known standard mixtures (Nu-Check, Elysian, MN).

RESULTS AND DISCUSSION

Quinoa seed composition

The overall composition of quinoa seed fractions is summarized in Table 1. With the exception of lipids,

Table 1. Quinoa seed fractions composition (% ± SD)[a]

Seed fraction	Moisture	Crude protein	Crude fibre	Total ash	Crude fat[b]	Total fat[c]
Whole seed	12·6 ± 0·04	13·7 ± 0·1	2·2 ± 0·04	2·8 ± 0·02	6·8 ± 0·02	7·6 ± 0·1
Hulls	11·3 ± 0·1	13·3 ± 0·1	5·6 ± 0·08	8·4 ± 0·13	5·7 ± 0·02	5·7 ± 0·1
Bran	13·9 ± 0·05	20·4 ± 0·1	5·0 ± 0·04	3·9 ± 0·03	11·0 ± 0·02	11·6 ± 0·1
Flour	15·6 ± 0·1	6·5 ± 0·1	0·4 ± 0·02	1·0 ± 0·17	2·8 ± 0·02	3·2 ± 0·05

[a] Data from Chauhan *et al.* (1992) except total fat.
[b] Fat extracted with diethyl ether.
[c] Fat extracted with water saturated *n*-butanol.

Table 2. Composition of lipids in quinoa (% ± SD)[a]

Seed fraction	Neutral lipids	Polar lipids	Free fatty acids
Whole seed	55·9 ± 0·6	25·2 ± 0·3	18·9 ± 0·2
Hulls	40·2 ± 0·6	44·4 ± 0·5	15·4 ± 0·1
Bran	76·2 ± 0·7	12·7 ± 0·1	11·1 ± 0·1
Flour	69·5 ± 0·5	21·1 ± 0·2	9·4 ± 0·1

[a] Results are averages of six replications.

these data were taken from earlier work in the authors' laboratory by Chauhan *et al.*, (1992). Total lipids were extracted with water saturated *n*-butanol (WSB) to prevent extraction of prolamins, which can interfere with lipid analysis (Morrison & Coventry, 1985). The amount of total lipids was higher than crude lipids extracted with diethyl ether using the Soxhlet method. This difference was attributed to the better extraction of polar lipids (Morrison & Coventry, 1985). Salun and Kalugina (1973) showed that the total amount of lipids in millet increased from 14·3 to 17·5% after extraction with chloroform–methanol and WSB, respectively. The highest amount of lipids was found in quinoa bran and whole seed, accounting for 11·6 and 7·6%, respectively. These results are in agreement with studies on sorghum and oats where bran was also shown to have the highest lipid content (Ruckenbauer, 1973; Rooney, 1978; Youngs, 1978). The crude lipid content of quinoa was similar to that found in *Amaranthus caudatus*, a plant closely related to quinoa (Saunders & Becker, 1978; Fernando & Bean, 1984).

Total lipids composition

The composition of quinoa lipids in whole seed and its milling fractions is shown in Table 2. Isolated lipids from SPE were checked for purity using TLC–FID which can detect lipid levels as low as 0·2 μg of compounds (Przybylski & Eskin, 1994). Proof of identity was confirmed by the addition of individual high purity standards to samples. Neutral lipids accounted for 40·2–76·2% of the total lipids in the seed fractions followed by 12·7–44·4% for the polar lipids. Free fatty acids (FFA) were high in all quinoa seed fractions ranging from 9·4% in the flour to 18·9% in whole quinoa seed. In wheat these compounds were present from 1·0 to 11·0%, while in germinating barley embryo from 2·8 to 8·4% (Holmer *et al.*, 1973) and in oats from 2·8 to 5·9% (Youngs, 1978). Rye and triticale flours also contained higher amounts of FFA which ranged over 4·8–13·8% and 3·6–16·7%, respectively (Chung & Tsen, 1974).

Neutral lipids

Further analysis of the neutral lipids in quinoa seed fractions is summarized in Table 3 which shows triglycerides as the major component present followed by diglycerides. TG contributed 71·7 and 87·2% of the total neutral lipids in quinoa hulls and flour, respectively. Neutral lipids are predominant in cereals, and have been reported to be around 90% in members of the Amaranths family (Opute, 1979). In comparison, DG accounted for 20·5 and 22·0% of the total neutral lipids in whole quinoa seed and hulls. Much lower levels of DG of around 3·0–12·1% were reported in wheat (Skarsaune *et al.*, 1970*a,b*), 1·6–4·8% in millet (Nechaev & Sandler, 1975) and 8·6–10·8% in rye (Chung & Tsen, 1974). Monoglycerides in quinoa ranged over 1·6–3·1% compared to 6·3–7·0% in rye (Chung & Tsen, 1974). The fraction referred to as waxes was not pure because it contained esterified sterols (ES) (Przybylski & Eskin, 1994). No data have been published about sterol esters content in grains of the Amaranths family, while in cereal grains these compounds can be present up to 8% of total lipids (Morrison, 1984).

Polar lipids

The polar lipids were separated into nine components by TLC and quantified by FID (Table 4). Identification of these compounds was confirmed by addition of known standards to authentic samples. The major phospholipids in whole quinoa seeds and hulls are lysophosphatidyl ethanolamine (LPE), phosphatidyl ethanolamine (PE), phosphatidyl inositol (PI), phosphatidyl choline (PC), phosphatidyl serine (PS) and lysophosphatidyl choline (LPC). PC and LPE were the main phospholipids in quinoa bran and flour, although the contributions of PE, PI and PS were still significant among the phospholipids identified. The content of LPE was unusually high in quinoa seeds and fractions. The amount of phospholipids extracted from cereal grains is highly dependent on the solvent and method of extraction used with quantification affected by type of detection method (Morrison & Coventry, 1985;

Table 3. Composition of neutral lipids of quinoa (% ± SD)[a]

Seed fraction	Triglycerides	1,2-Diglycerides	1,3-Diglycerides	Monoglycerides	Waxes[b]
Whole seed	73·7 ± 0·6	13·2 ± 0·2	7·3 ± 0·1	3·1 ± 0·1	2·7 ± 0·1
Hulls	71·7 ± 0·5	11·3 ± 0·2	10·7 ± 0·1	4·7 ± 0·1	2·2 ± 0·1
Bran	82·1 ± 0·1	8·4 ± 0·1	4·6 ± 0·1	1·8 ± 0·1	3·2 ± 0·1
Flour	87·2 ± 0·5	6·3 ± 0·1	3·7 ± 0·1	1·6 ± 0·1	1·1 ± 0·1

[a] Results are averages of six replications.
[b] Waxes contained esterified sterols.

Table 4. Compositions of polar lipids isolated from quinoa (% ± SD)[a]

Compound[b]	Whole seed	Hull[b]	Bran[b]	Flour[b]
PA	1·1 ± 0·1	0·6 ± 0·03	0·5 ± 0·02	0·4 ± 0·02
PS	4·0 ± 0·1	3·1 ± 0·04	3·9 ± 0·04	2·7 ± 0·04
PE	18·5 ± 0·2	19·8 ± 0·1	13·4 ± 0·1	8·3 ± 0·04
PI	10·5 ± 0·1	9·6 ± 0·1	5·8 ± 0·04	12·8 ± 0·1
LPE	43·2 ± 0·2	43·3 ± 0·2	22·3 ± 0·2	16·6 ± 0·1
PC	12·3 ± 0·1	15·6 ± 0·1	48·3 ± 0·1	49·0 ± 0·1
LPC	3·6 ± 0·1	2·9 ± 0·1	4·2 ± 0·1	3·4 ± 0·1
MGDG	1·6 ± 0·03	1·2 ± 0·01	0·4 ± 0·01	2·7 ± 0·04
DGDG	2·8 ± 0·04	1·9 ± 0·02	0·9 ± 0·02	3·9 ± 0·05
Others[c]	3·2 ± 0·1	2·6 ± 0·1	0·4 ± 0·02	0·2 ± 0·01

[a] Results are averages of six replications.
[b] Polar lipids: PA, phosphatidic acid; PS, phosphatidyl serine; PE, phosphatidyl ethanolamine; PI, phosphatidyl inositol; LPE, lysophosphatidyl ethanolamine; PC, phosphatidyl choline; LPC, lysophosphatidyl choline; MGDG, monogalactosyl diglyceride; DGDG, digalactosyl diglyceride.
[c] Components no identified.

Geiss, 1987). Phospholipids are generally detected after separation on TLC by charring, and the intensity of the charred spot is different between PC and LPC and between PE and LPE. Consequently, the amount of LPC and of LPE is often underestimated (Osagie & Kates, 1984). Using FID and calibration for each component separately, a higher accuracy was achieved by the direct measurement of these components (Przybylski & Eskin, 1991). High levels of LPC and LPE, 42 and 21% respectively, have been reported in millet (Osagie & Kates, 1984), while de la Roche *et al.* (1973) reported 14% LPE in wheat with very low levels of LPC. The predominance of PC, 49%, among the phospholipids of quinoa flour was similar to that found in rye flour (Chung & Tsen, 1974). Opute (1979) reported three phospholipids in Amaranthus seeds, namely PE, PC and PI which accounted for 13·3, 16·3 and 8·2% of the total phospholipids present, respectively. These values were fairly close to the levels reported in this study for quinoa seeds (Table 4). The content of MGDG and DGDG were in the range 0·5–2·7% and 0·9–3·9%, respectively. Similar ranges of these compounds were found in seeds of Amaranths (Opute, 1979). Additional components were observed on galactolipids chromato-

Table 5. Fatty acids composition of lipid extract and major lipid classes of quinoa (%)[a]

Acid	Lipids extracts				Neutral lipids				Polar lipids				Free fatty acids			
	WSD[b]	Hull	Bran	Flr.[c]	WSD	Hull	Bran	Flr.	WSD	Hull	Bran	Flr.	Wsd	Hull	Bran	Flr.
C12:0	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	ND	ND	ND	ND	ND	0·1	0·1	0·1
C13:0	0·2	0·1	0·1	0·1	0·2	0·3	0·2	0·3	0·6	0·5	0·8	0·1	0·6	0·2	ND	0·4
C14:0	0·2	0·5	0·2	0·3	0·3	0·6	0·3	0·3	0·2	0·5	0·4	0·6	0·4	0·5	0·7	1·3
C15:0	0·1	0·1	0·1	0·1	0·1	0·2	0·1	0·1	0·3	0·6	0·2	0·2	0·1	0·3	0·2	0·8
C16:0	9·6	11·2	9·9	10·4	8·3	10·1	8·9	9·1	15·7	15·3	15·5	12·5	11·7	12·0	12·6	12·9
C16:1	0·1	0·2	0·1	0·2	0·1	0·1	0·2	0·1	1·1	0·4	0·4	0·2	0·2	0·3	0·2	0·3
C16:2	0·3	0·1	0·1	0·2	0·1	0·1	0·1	0·1	0·2	ND	0·1	0·2	0·5	0·4	0·2	0·7
C17:0	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	ND	0·1	0·1	0·2
C18:0	0·6	0·9	0·5	0·5	0·7	1·1	0·6	0·8	1·0	0·9	0·8	1·2	1·4	1·8	1·9	3·5
C18:1	21·1	20·2	20·3	19·4	22·4	21·5	21·2	20·0	16·0	16·9	15·0	26·1	20·3	22·1	20·2	18·5
C18:2	56·0	53·6	56·9	57·3	55·9	53·1	56·4	56·3	57·2	56·8	58·1	53·2	52·2	50·7	52·0	49·4
C18:3	6·7	7·3	7·6	6·9	6·7	7·5	7·3	7·7	4·9	5·8	5·7	3·5	6·9	6·4	7·5	5·8
C20:0	0·4	0·6	0·3	0·3	0·4	0·6	0·4	0·5	0·1	0·2	0·6	0·1	0·5	0·4	0·3	0·4
C20:1	1·2	1·3	1·1	1·0	1·3	1·4	1·2	1·3	0·3	0·3	0·4	0·5	1·4	1·3	1·3	1·1
C20:2	0·3	0·4	0·1	0·2	0·2	0·2	0·2	0·3	0·2	0·2	ND	0·2	0·5	0·2	0·2	0·3
C21:0	0·2	0·2	0·1	0·1	0·2	0·1	0·2	0·2	0·1	ND	ND	0·1	0·2	0·2	0·1	0·1
C22:0	0·7	0·8	0·5	0·6	0·6	0·7	0·5	0·5	0·6	0·5	0·8	0·3	0·6	0·7	0·6	0·7
C22:1	1·3	1·3	1·2	1·2	1·4	1·5	1·1	1·4	0·3	0·2	0·4	0·3	1·5	1·3	1·2	1·1
C22:2	0·3	0·5	0·2	0·2	0·2	0·1	0·2	0·4	ND	ND	ND	ND	0·2	0·1	0·1	0·1
C24:0	0·3	0·3	0·3	0·7	0·4	0·2	0·2	0·2	0·8	0·6	0·6	0·4	0·4	0·5	0·4	0·9
C24:1	0·2	0·2	0·2	0·2	0·3	0·4	0·2	0·2	0·3	0·2	0·1	0·2	0·4	0·4	0·1	1·4
CSD[d]	2·1	1·9	2·0	1·8	1·6	2·0	1·8	2·4	2·3	2·2	2·0	2·1	2·6	2·0	2·0	1·9

[a] Average values for two samples run in duplicate.
[b] Whole quinoa seed.
[c] Quinoa flour.
[d] Average coefficient of standard deviation calculated for all analyzed fatty acids.

Table 6. Fatty acid composition of lipid extract and major lipid classes of quinoa (%)[a]

Acid	Triglycerides				Diglycerides				Monoglycerides				Waxes			
	WSD[b]	Hull	Bran	Flr.[c]	WSD	Hull	Bran	Flr.	WSD	Hull	Bran	Flr.	WSD	Hull	Bran	Flr.
C12:0	0·1	0·1	0·1	0·1	ND	0·3	ND	0·1	ND	0·2	ND	0·1	0·3	0·2	ND	ND
C13:0	0·3	0·4	0·1	0·1	0·6	1·4	0·2	0·3	0·1	0·1	0·2	ND	0·9	0·7	0·3	0·3
C14:0	0·2	0·3	0·3	0·2	0·5	0·8	0·2	0·5	0·3	1·5	0·2	0·7	1·2	0·9	0·3	0·3
C15:0	0·1	0·1	0·1	0·6	0·5	0·5	0·3	0·8	0·2	0·4	ND	0·1	0·3	0·2	0·1	0·1
C16:0	8·3	8·6	9·0	7·8	8·7	11·8	9·8	11·6	4·9	10·9	6·0	8·4	5·2	5·0	3·0	3·0
C16:1	0·2	0·2	0·2	0·2	0·2	0·4	0·1	0·4	0·4	0·4	0·2	0·3	0·4	0·2	0·5	0·4
C16:2	0·1	0·1	0·1	0·1	0·2	ND	0·1	ND	0·1	0·1	0·1	0·1	0·4	0·3	0·1	0·2
C17:0	0·1	0·1	0·1	0·1	0·2	0·3	ND	0·2	0·1	0·3	ND	0·1	0·2	0·1	0·2	0·2
C18:0	0·6	0·7	0·6	0·7	0·7	1·7	0·7	1·2	0·9	2·8	0·8	1·4	1·5	1·6	2·3	0·9
C18:1	23·0	22·6	22·1	23·9	23·9	23·9	22·2	30·9	22·1	18·1	18·2	18·5	12·3	14·1	31·7	0·9
C18:2	54·8	54·7	55·0	55·0	55·6	47·5	57·1	47·1	59·6	53·0	62·7	58·7	11·4	10·8	6·3	4·9
C18:3	6·8	7·7	7·4	6·6	4·4	4·9	4·9	3·8	8·5	8·8	9·1	8·3	0·5	0·4	0·5	0·4
C20:0	0·6	0·4	0·4	0·4	0·4	0·9	0·4	0·3	0·2	0·3	0·2	0·4	0·4	0·6	0·3	0·2
C20:1	1·4	1·4	1·3	1·4	1·3	1·4	1·3	1·1	0·7	0·8	0·7	0·6	0·3	0·9	0·5	ND
C20:2	0·2	0·2	0·2	0·2	0·2	0·2	0·3	ND	0·2	0·3	0·3	ND	0·4	0·2	0·2	0·6
C21:0	0·2	0·1	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·1	0·1	0·1	0·1	ND	ND	0·1
C22:0	0·6	0·4	0·5	0·4	0·6	1·0	0·6	0·3	0·4	0·2	0·3	0·4	0·7	0·6	0·2	0·2
C22:1	1·6	1·3	1·4	1·2	1·2	1·3	1·1	0·9	0·5	0·6	0·4	0·6	0·2	0·1	0·2	0·1
C22:2	0·3	0·1	0·4	0·2	0·2	0·2	0·1	ND	0·2	0·2	0·1	0·2	1·2	0·7	0·4	1·0
C24:0	0·3	0·3	0·3	0·3	0·3	0·9	0·3	0·3	0·3	1·1	0·3	0·8	62·1	62·2	58·8	82·5
C24:1	0·2	0·2	0·2	0·3	0·1	0·4	0·1	ND	0·1	0·1	0·1	0·2	0·2	0·2	0·1	ND
CSD[d]	2·1	1·9	2·2	2·0	1·8	2·7	1·9	2·4	2·6	2·8	3·2	2·1	2·8	2·6	2·5	3·0

[a] Average values for two samples run in duplicate.
[b] Whole quinoa seed.
[c] Quinoa flour.
[d] Average coefficient of standard deviation calculated for all analyzed fatty acids.

grams but were not identified due to the lack of appropriate standards. The contribution of monogalactosyl diglycerides (MGDG) and digalactosyl diglycerides (DGDG) was relatively low in comparison to the values observed in millet and wheat: 11·7 and 15·4%; 5·4 and 17·6%, respectively (Lin *et al.*, 1974; Osagie & Kates, 1984).

Fatty acids

Fatty acid analysis of the different lipid fractions in quinoa are summarized in Tables 5 and 6. Linoleic acid (C18:2) accounted for over 50% of the fatty acids in all fractions with the exception of the waxes. Oleic acid (C18:1) was next highest followed by palmitic acid (C16:0). The contribution of linolenic acid (C18:3) was relatively high in quinoa lipids, over 6%; this still further indicates the excellent nutritional quality of this grain. The fatty acids composition is similar to the results published by Ruales and Baboo (1993). The fatty acid composition of quinoa lipids is similar to that reported for wheat (Morrison, 1984), barley (Skarsaune *et al.*, 1972), rye (Silanteva & Snegireva, 1969) and triticale (Lorenz & Maga, 1975). Quinoa phospholipids were high in C16:0 as shown previously in wheat and millet phospholipids (Morrison, 1984; Osagie & Kates, 1984). Of particular interest is the presence of linolenic acid (C18:3) which was at much higher levels than found in other cereals (Morrison, 1984). The major fatty acid in the wax fraction was lignoceric acid (C24:0) which accounted for 52·8% of the total wax in the bran compared to 82·5% in the flour. This indicates that the major components in the wax fraction were long chain saturated fatty acids (Rezanka, 1989). With respect to the neutral lipid fractions, linoleic, oleic and palmitic acids were the major fatty acids present in decreasing order of magnitude, respectively.

The data presented in this paper indicate that quinoa lipids are generally quite similar in composition to that reported for other cereal crops (Morrison, 1984).

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