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Effect of harvest time on seed oil and protein contents and compositions in the oleaginous gourd *Lagenaria siceraria* (Molina) Standl

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Abstract

BACKGROU ND: The stage of fruit ripeness at the time of harvest determines the final quality of ripe fruit. In this study, changes in the chemical composition of seed kernels from the oleaginous gourd *Lagenaria siceraria* (Molina) Standl. during maturation were evaluated to determine the best time to harvest the berries. Two cultivars (round and oval berry) were studied at three maturation stages (30 and 50 days after fruit set (DAFS) and complete plant whiteness (CPW)).

RESULTS: Seed kernels were rich in oil (527.2-544.6 g kg^{-1}), protein (402.8-403.3 g kg^{-1}), minerals and energy. Maturation influenced the chemical compounds of the two cultivars differently. Best quantities of these components were reached at 50 DAFS. However, protein bioavailability was better at 30 DAFS and CPW in the round and oval berry cultivars respectively. *Lagenaria siceraria* oils were of good quality, containing an abundance of essential fatty acids (647.2-667.0 g kg^{-1}).

CONCLUSION: Both cultivars of *L. siceraria* should be harvested at 50 DAFS owing to the good nutritional properties of their seeds and oils. However, to obtain best-quality proteins, round and oval berry cultivars should be harvested at 30 DAFS and CPW respectively. The results of this study will be useful in reducing the production time of fruits and improving the nutritional quality of their seeds, c 2011 Society of Chemical Industry

Keywords: *Lagenaria siceraria* berries; maturation stages; seed composition; oil; protein bioavailability

INTRODUCTION

Nowadays, the contribution of underutilised crops to the food security and economic prosperity of rural populations in the developing countries is widely recognised by both public and private authorities. The Cucurbitaceae are among the most economically important vegetables. In West Africa at least five species of indigenous cucurbits are regularly cultivated on a small scale for their oleaginous seeds, generally by women.[1] The dried and slightly roasted kernels are transformed into a paste for consumption as a sauce thickener. Biochemical studies have revealed high nutritional potential of this crop family. The seeds are rich in lipids, proteins and energy.[2] Moreover, these plants are of great socio-economic importance owing to several cultural events associated with their use in Sub-Saharan Africa. The commerce of their seeds brings substantial incomes to producers. In several countries of Sub-Saharan Africa such as Ivory Coast, Benin and Nigeria, *Lagenaria siceraria* is the most cultivated oleaginous cucurbit[3] owing to its high agronomic potential. Three cultivars of *L. siceraria* distinguishable by their fruit shape and size have been described in Ivory Coast.[1] This species is also the richest oleopro-teaginous plant in terms of macronutrient content, the average content of lipids and proteins reaching 856 g kg^{-1},[4] compared with 753.7 g kg^{-1} for groundnut[2] and 550 g kg^{-1} for soybean.

In the traditional farming system, fruits are harvested at complete whiteness of the plants.[5] The harvested fruits are often stored on-farm for an undetermined time before the extraction of seeds take place. Such cultural practices do not optimise the yield quality in terms of the contents and quality of seed nutrients. Indeed, it has been demonstrated in several non-perennial crops that fruits and seeds can reach morphological and

physiological maturity before plant senescence.[6] In fact, during the growth of fruits, biochemical compounds can undergo significant quantitative and qualitative variation.[7]

Because the stage of fruit ripeness at the time of harvest determines the final quality of ripe fruit, many studies on the identification of physical and chemical indices of maturity in commercial fruit-producing crops have been reported.[8] The physical indices are mainly related to fruit colour, seed and fruit weight and fruit firmness.[9] Physiological maturity occurs when chemicals reach their highest quantitative and qualitative levels in fruits or seeds.[10] Various maturity indices have thus been identified and used to monitor fruit development in order to determine the appropriate harvest window for several crops.

To our knowledge, no information is available on the relationship between changes in chemical contents and harvest time in *Lagenaria siceraria.* Since the identification of crop maturation stages at which chemicals are at their highest contents and best quality is helpful for plant breeders and nutritionists, we monitored the contents and compositions of proteins and lipids in two widely grown cultivars of the oleaginous gourd *L. siceraria* at three harvest times. The results of this study will allow the determination of the appropriate window for harvest.

MATERIALS AND METHODS

Experimental site, plant material and cropping practice

The experiment was conducted from July to November 2007 atthe experimental station of the University of Abobo-Adjame (Abidjan, Ivory Coast) (latitude between 5° 17' and 5° 31' N, longitude between 3° 45' and 4° 22' W). During this period, rainfall, mean temperature and humidity varied from 5.33 to 192.28 mm, from 23.3 to 26.4 °C and from 86.7 to 96% respectively. Open-pollinated accessions from two edible-seeded *L. siceraria* (Molina) Standl. cultivars recognisable by their fruit shape (oval or round) were used. Seeds from the round fruit cultivar are characterised by the presence of a cap on the distal side, whereas those from the oval fruit cultivar lack this cap. Differences are also noted between the two cultivars in their rates of seed germination and seedling emergence, the best performances being observed for the round fruit cultivar. However, the visual changes in fruits during their growth as well as at plant whiteness are the same in the two cultivars. Both round and oval fruit cultivars were obtained from thecucurbitgermplasm of the university, wheretheyareidentified by the alphanumeric codes NI354 and NI260 respectively. Each cultivar was sown on a plot of 20 m × 20 m in 12 holes. Female flowers were tagged after their closure in order to monitor the fruits until the date determined for harvesting. Fruits were harvested at three stages of maturation: (i) 30 days after fruit set (DAFS), at which stage fruits do not grow any more; (ii) 50 DAFS, at which stage the colour of fruits no longer changes; (iii) complete plant whiteness (CPW), indicating the end of plant growth. For each of the three fruit maturation times, five fruits per cultivar were selected. The seeds were extracted from each fruit, washed and dried in the sun for 1 week. After drying, the seeds of all five fruits were grouped and decorticated to obtain seed kernels that were used for analysis.

Proximate and mineral composition

The moisture content of L *siceraria* seed kernels was determined gravimetrically by heating the material (1 g) in an oven at 105 °C for 24 h.[11] Crude protein (N × 6.25) content was estimated from 100 mg of crushed seed according to the Kjeldahl method.[11] Crude fat of the sample (15 g) was extracted with *n*-hexane in a Soxhlet apparatus for 6 h. The solvent was removed in a rotavapor at 40°C.

Ash content was determined gravimetrically after dry mineralisation of the sample (500 mg) in a muffle furnace at 550 °C.[11] Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were determined by hot sequential digestion of the sample according to the method of Van Soest.[12,13] Gross energy from 800 mg of sample was determined by measuring the heat of combustion of seeds by means of a Parr 1241 adiabatic calorimetric bomb (Parr Instrument Company, Moline, IL, USA) in the presence of oxygen. Minerals were analysed from 800 mg of grinded seed kernels after digestion by 7 ml concentrated nitric acid and 300 mL L^{-1} hydrogen peroxide (6:1 v/v). Calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg) were analysed separately using a Perkin Elmer 1100B atomic absorption spectrophotometer (Perkin Elmer, Norwalk, CT, USA). Sodium (Na) and potassium (K) were measured using a flame emission photometer (Eppendorf, Hambourg, Germany). Phosphorus (P) content was determined by the phosphomolybdate method.[11]

Quality of protein

The amino acid composition of seed kernels was determined by acid hydrolysis (3 mol L^{-1} HCl) under nitrogen at 110°C for 24 h followed by liquid chromatography (HPLC) analysis (Biochrom 20 Plus, Pharmacia, Cambridge, UK).[14] Cystine and methionine were determined after performic acid oxidation according to Commission Directive 98/64/EC.[15] Tryptophan was determined by alkaline hydrolysis of proteins followed by HPLC analysis (Spectra Physics 8800, San Jose, CA, USA) according to Commission Directive 2000/45/EC.[16]

The *in vitro* protein digestibility of 150 mg of seed kernels was estimated using the multienzyme method of Pedersen and Eggum as recommended by the FAO/WHO.[17] Porcine pancreatic trypsin (23.1 units mL^{-1}; T0303, Sigma-Aldrich (St. Louis, MO, USA)), porcine intestinal peptidase (0.052 units mL^{-1}; P7520, Sigma (Bornem, Belgium)) and bovine pancreatic chymotrypsin (186 units mL^{-1};C4129 II, Sigma) were used. The protein chemical score (CS) was calculated according to the procedure suggested by the FAO/WHO[17] as the ratio of the concentration a_i of the amino acid in shortest supply (restrictive amino acid) to the concentration a_s of this amino acid in the standard protein: $CS = (a_i a_s) \times 100$. The protein digestibility-corrected amino acid score (PDCAAS) was calculated by multiplying the lowest chemical index by the *in vitro* digestibility of protein: PDCAAS = (CS × digestibility)/100.

Quality of oil

The acid value (NF T60-204) and unsaponifiable matter (NF T60-205) of the oil extracted from seed kernels were determined by AFNOR methods.[18] The peroxide value (Cd 8b-90), saponification index (Cd 3a-94) and iodine value (Cd 1c-85) were determined using AOCS methods.[19] The evaluation of oil colour was based on the colour scale of Gardner described in ISO 4630-1. The oxidative stability of the oil was evaluated with a Rancimat 679 apparatus (Metrohm AG, Herison, Switzerland) and expressed as oxidation induction time (h), which is the period for which the oil resists to oxidation under well-defined conditions (2.5 g of oil heated at 100°C under a purified air flow of 15 L h^{-1}). To establish the fatty acid composition, the fatty acids in 10 mg of oil were first converted to their methyl esters (FAMEs) with a mixture of boron trifluoride and methanol (14:86 w/v) according to the method of Morrison and Smith.[20] Then the extracted FAMEs were dissolved in pure hexane for gas chromatography analysis (HP 6890, Agilent technologies, Brussels, Belgium) with flame ionisation detection. A 1 µL aliquot of FAME sample was injected onto a VarianCP 9205 (Sint-Katelijne-Waver, Belgium) capillary column (30 m length,0.25 mm diameter, 0.25 µm film thickness). A standard mixture of 37 fatty acids (Supelco, Bellefonte, PA, USA) was used for identification. The identification was confirmed by gas chromatography/mass spectrometry.

Statistical analysis

For each parameter examined, an analysis of variance (ANOVA) was performed using the SAS statistical package.[21] Sodium, heptadecanoic acid, palmitoleic acid, methionine, digestibility and PDCAASdata were logarithmically transformed ($\log(x + 1)$) to achieve homogeneity of variance. When a significant difference was observed between the stages of maturation for a parameter, the ANOVA was supplemented with the Gupta test to determine the stages of fruit maturation at which significantly higher values of a given parameter were observed.

RESULTS

Proximate and mineral analysis

Results of the chemical analysis of crushed dried seed kernels from both cultivars of *L. siceraria* are given in Table 1. Among the eight parameters related to the proximate composition, four and six could differentiate statistically ($P \leq 0.05$) the stages of maturation in the round and oval berry cultivars respectively. The highest number of parameters presenting their highest values was observed at 50 DAFS in both cultivars (NDF, ADF and ADL for the round berry cultivar and crude fat, NDF, ADF and energy for the oval berry cultivar). Four major minerals (K, P, Ca and Mg) showed significant differences among seed maturation stages in the round berry cultivar. Potassium, P and Mg predominated in seeds of the round berry cultivar harvested at 30 DAFS while Ca predominated in seeds harvested at 50 DAFS. No significant differences were noted among seed maturation stages in the oval berry cultivar for all minerals examined except Ca. The contents of the four minor minerals examined as well as those of Mn and Zn varied significantly in both cultivars. The highest number of the indicated minerals expressing the highest concentration values was observed at 50 DAFS in the round berry cultivar, while no clear trend was observed in the oval berry cultivar. There was no significant difference ($P > 0.05$) in toxic mineral (As, Hg, Pb and Cd) contents among seed maturation stages in both cultivars. Overall, the results indicated that the appropriate physiological seed maturation window in both cultivars analysed was 50 DAFS.

Amino acid composition

The amino acid compositions of proteins from kernels of the two analysed cultivars are shown in Table 2. Among 11 essential amino acids, the contents of nine and ten were significantly different ($P \leq 0.05$) among maturation stages in the round and oval berry cultivars respectively. The highest numbers of amino acids with significantly high concentrations were observed in seeds from berries harvested at 30 DAFS in both cultivars and at CPW in the oval berry cultivar. The contents of cystine, methionine and proline did not vary significantly among fruit maturation stages in the round berry cultivar. In the oval berry cultivar, only methionine did not vary significantly in content with respect to the fruit maturation stage.

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Table 1. *Chemical characteristics (dry matter basis) of Lagenaria siceraria seed kernels at different maturation stages*

	Round berry (sample size *n* = 4)			Oval berry (sample size *n* = 4)		
Characteristic[a]	**30 DAFS**	**50 DAFS**	**CPW**	**30 DAFS**	**50 DAFS**	**CPW**
Proximate composition (g kg^{-1})						
Moisture	72.7 ± 12.0	60.0 ± 1.4	59.7 ± 1.2	59.4 ± 2.3	58.5 ± 4.0	59.4 ± 2.2
Protein (N × 6.25)	398.4 ± 4.8	402.8 ± 3.4	394.7 ± 1.6	439.2 ± 2.6a	403.3 ± 1.2b	380.8 ± 3.3b
Crude fat	480.5 ± 0.7	527.2 ± 22.4	505.8 ± 34.4	449.9 ± 5.3b	544.6 ± 1.9a	510.7 ± 2.5b
Neutral detergent fibre	58.7 ± 2.7b	63.4 ± 0.9a	50.5 ± 1.8b	62.9 ± 2.9a	65.3 ± 1.1a	38.7 ± 2.7b
Acid detergent fibre	28.1 ± 1.6b	38.1 ± 2.0a	26.7 ± 2.1b	29.7 ± 2.0a	28.2 ± 1.5a	24.3 ± 1.7b
Acid detergent lignin	5.8 ± 1.0b	7.5 ± 1.3a	0.4 ± 0.4b	1.3 ± 0.8	3.4 ± 1.2	1.1 ± 0.9
Ash	38.0 ± 2.5	36.4 ± 1.9	37.0 ± 0.6	43.2 ± 2.6a	42.4 ± 0.6a	36.5 ± 1.3b
Energy (kcal kg^{-1})	5670 ± 90b	5980 ± 50a	5920 ± 10a	5590 ± 10b	5850 ± 20a	5890 ± 10a
Major minerals (g kg^{-1})						
Potassium (K)	6.17 ± 0.00a	5.26 ± 0.14b	5.62 ± 0.09b	6.05 ± 0.20	5.60 ± 0.08	5.56 ±0.01
Sodium (Na)	0.05 ± 0.00	0.04 ± 0.00	0.05 ± 0.00	0.04 ± 0.00	0.03 ± 0.00	0.04 ± 0.00
Phosphorus (P)	14.83 ± 0.34a	9.87 ± 0.13b	10.53 ± 0.33b	12.38 ± 0.58	11.82 ± 0.01	9.73 ± 1.19
Calcium (Ca)	0.54 ± 0.00b	0.78 ± 0.01a	0.62 ± 0.00b	1.03 ± 0.02a	0.84 ± 0.01b	0.98 ± 0.00b
Magnesium (Mg)	7.63 ± 0.02a	6.49 ± 0.05b	6.79 ± 0.08b	7.48 ± 0.22	7.38 ± 0.06	6.70 ± 0.26
Trace minerals (mg kg^{-1})						
Manganese (Mn)	20.381 ± 0.153b	24.894 ± 0.451a	18.186 ± 0.000b	31.629 ± 0.677a	23.209 ± 0.225b	24.133 ± 0.000b
Iron (Fe)	82.442 ± 0.534a	80.000 ± 2.257a	67.374 ± 0.376b	111.311 ± 4.811	108.768 ± 1.202	84.254 ± 16.764
Copper (Cu)	22.107 ± 0.076b	24.521 ± 0.451a	24.248 ± 0.075a	31.256 ± 0.376	31.441 ± 0.976	31.841 ± 0.150
Zinc (Zn)	77.535 ± 4.118a	63.405 ± 1.805b	65.194 ± 0.301b	79.895 ± 0.226a	80.036 ± 2.178a	70.590 ± 1.955b
Toxic minerals (mg /kg^{-1})						
Arsenic (As)	0.004 ± 0.006	0.045 ± 0.064	0.047 ± 0.067	0.017 ± 0.024	0.005 ± 0.007	0.001 ± 0.002
Mercury (Hg)	0.007 ± 0.005	0.022 ± 0.011	0.018 ± 0.000	0.007 ± 0.000	0.007 ± 0.000	0.013 ± 0.003
Lead (Pb)	0.018 ± 0.026	0.031 ± 0.044	0.062 ± 0.000	0.044 ± 0.062	0.031 ± 0.034	0.062 ± 0.088
Cadmium (Cd)	0.016 ± 0.007	0.012 ± 0.002	0.024 ± 0.002	0.015 ± 0.002	0.027 ± 0.008	0.020 ± 0.007

[a] For each characteristic, mean values followed by 'a' were the higher averages and mean values followed by 'b' were the lower averages based on the Gupta test at 0.05 level; mean values without letters were not significantly different ($P > 0.05$).

Biological value of proteins

The results related to the variation in the biological value of proteins in the two cultivars of *L. siceraria* are shown in Table 3. They revealed that lysine was the limiting amino acid in both cultivars at all fruit maturation stages. This amino acid reached its highest content at 30 DAFS (67.86%) in the round berry cultivar. In the oval berry cultivar the highest concentration of lysine was observed at CPW (65.97%). Significant differences were also noted among fruit maturation stages in both cultivars for protein digestibility and PDCAAS. The digestibility index showed the best values in seed kernels from berries harvested at 30 DAFS (56.9%) and CPW (55.0%) in the round and oval berry cultivars respectively.

Physicochemical properties and stability of oil

Table 4 shows the variation in the physicochemical properties of seed kernel oil from the two cultivars of *L. siceraria* during fruit maturation. The results indicated that five parameters differed significantly in the round berry cultivar whereas four parameters varied in the oval berry cultivar ($P \leq 0.05$). The maximum acid, peroxide and colour values of oil from the round berry cultivar were obtained at 30 DAFS. The iodine value was higher at withering (CPW), while the oxidation induction time was higher in seeds harvested at 30 and 50 DAFS. In the oval berry cultivar the lowest acid values were observed at 30 DAFS and CPW, in contrast to the iodine values that were highest at 30 and 50 DAFS.

Fatty acid composition

Table 5 presents the patterns of fatty acid variation in the oil from *L. siceraria* during fruit maturation. Highly significant differences were observed ($P \leq 0.001$) among fruit maturation stages for all 13 fatty acids analysed in the round berry cultivar. In the oval berry cultivar, only myristic acid did not vary significantly with the respect to the fruit maturation stage. The highest numbers of fatty acids with significantly high concentrations were obtained at 30 DAFS in both cultivars.

Table 2. *Amino acid composition (g amino acid kg^{-1} dry matter) of Lagenaria siceraria seed kernels at different maturation stages*

	Round berry (sample size *n* = 3)			Oval berry (sample size *n* = 3)		
Amino acid[a]	**30 DAFS**	**50 DAFS**	**CPW**	**30 DAFS**	**50 DAFS**	**CPW**
Essential						
Cystine	6.2 ± 0.8	4.9 ± 0.0	5.0 ± 0.1	5.2 ± 0.2a	4.6 ± 0.1b	5.1 ± 0.0a
Histidine	10.9 ± 0.0a	10.3 ± 0.1b	10.4 ± 0.1b	11.2 ± 0.2a	10.1 ± 0.0b	11.4 ± 0.0a
Isoleucine	14.2 ± 0.0a	13.3 ± 0.1b	13.3 ± 0.1b	13.9 ± 0.1b	12.9 ± 0.1b	14.3 ± 0.1a
Leucine	22.0 ± 0.1a	20.4 ± 0.2b	20.6 ± 0.2b	21.5 ± 0.2b	19.8 ± 0.0b	22.1 ± 0.1a
Lysine	13.6 ± 0.1a	11.5 ± 0.1b	11.6 ± 0.1b	13.6 ± 0.5a	11.4 ± 0.0b	12.5 ± 0.1b
Methionine	8.3 ± 0.6	8.0 ± 0.1	7.8 ± 0.4	8.6 ± 0.1	8.7 ± 1.6	8.8 ± 0.0
Phenylalanine	17.8 ± 0.1a	16.9 ± 0.3b	16.9 ± 0.2b	17.5 ± 0.2	16.3 ± 0.0b	18.6 ± 0.0a
Threonine	11.6 ± 0.0a	10.7 ± 0.1b	11.0 ± 0.2b	11.6 ± 0.2a	10.4 ± 0.0b	11.9 ± 0.1a
Tryptophan	6.4 ± 0.0b	7.1 ± 0.0a	6.1 ± 0.0b	6.6 ± 0.2a	5.8 ± 0.0b	6.8 ± 0.0a
Tyrosine	10.3 ± 0.0a	9.6 ± 0.1b	9.6 ± 0.1b	10.1 ± 0.1b	9.3 ± 0.0b	10.5 ± 0.0a
Valine	17.8 ± 0.2a	16.0 ± 0.2b	16.2 ± 0.1b	17.5 ± 0.1a	15.7 ± 0.1b	17.2 ± 0.1a
Non-essential						
Alanine	15.5 ± 0.1a	14.1 ± 0.2b	14.1 ± 0.2b	15.1 ± 0.2a	13.7 ± 0.0b	15.2 ± 0.1a
Arginine	46.8 ± 0.4a	43.1 ± 0.4b	43.2 ± 0.3b	49.3 ± 0.4a	43.0 ± 0.0b	46.1 ± 0.2a
Aspartic acid	27.5 ± 0.2a	24.7 ± 0.2b	25.3 ± 0.2b	27.3 ± 0.2a	24.5 ± 0.0b	27.2 ± 0.1a
Glutamicacid	51.5 ± 0.2a	45.4 ± 0.4b	48.0 ± 0.2b	52.1 ± 0.5a	45.8 ± 0.0b	50.6 ± 0.1b
Glycine	16.9 ± 0.0a	15.6 ± 0.2b	16.0 ± 0.1b	17.9 ± 0.2a	15.2 ± 0.1b	17.1 ± 0.1b
Proline	11.8 ± 0.1	11.4 ± 0.1	11.3 ± 0.4	11.6 ± 0.0b	10.6 ± 0.2b	12.2 ± 0.2a
Serine	13.5 ± 0.0a	12.6 ± 0.0b	13.2 ± 0.2a	13.9 ± 0.4a	12.6 ± 0.0b	14.5 ± 0.1a

[a] For each amino acid, mean values followed by 'a' were the higher averages and mean values followed by 'b' were the lower averages based on the Gupta test at 0.05 level; mean values without letters were not significantly different ($P > 0.05$).

DISCUSSION

During the growth of fruits, biochemical compounds can undergo significant quantitative and qualitative changes.[7] Determining accurately the optimum harvesting time for a given crop improves the quality and quantity of seeds produced. Data from such an investigation are useful for crop husbandry optimisation. The variation in proximate composition and nutrient and mineral contents in relation to fruit maturation stage in the oleaginous gourd *L. siceraria* revealed relevant trends.

Proximate composition and minerals

The variation in proximate composition and energy showed different trends according to cultivar. In the round berry cultivar, as maturation proceeded, the proximate composition increased until 50 DAFS and then decreased, while that of the oval berry cultivar presented constant values that decreased after 50 DAFS. Such contrasting trends in the variation in proximate composition with respect to crop variety are widely reported.[22] These variations can result from a combination of several factors, chiefly genetics, sunlight, reliable rainfall, topography, soil, location, season, fertilisation of soil and maturity.[22,23] The highest contents of the majority of compounds analysed were reached around 50 DAFS and then remained constant or decreased according to cultivar. These results suggested that the berries were mature at this time. At this stage the crude protein and fat contents of *L. siceraria* were similar to these reported for other oleaginous cucurbits such as indigenous watermelon (protein 357 g kg^{-1} fat 501 g kg^{-1}), pumpkin (protein 365-375.5 g kg^{-1}, fat 510.1 -558 g kg^{-1}) and 'Egussi' melon (protein 314.1 g kg^{-1}, fat 439.3 g kg^{-1}).[24,25] At 50 DAFS the contents of protein and fat were higher than those found in the dried kernels of a peanut (*Arachis hypogaea* L) landrace widely cultivated in the target zone.[2] It is worth noting that, based on their uses, peanut is the principal crop that competes with oleaginous cucurbits in the target region. The seed kernel of the oleaginous gourd *L. siceraria* contained significant amounts of minerals. The contents of certain minerals (K, P, Mg, Fe, Zn and Mn) at 50 DAFS were higher than those found previously in the same species.[26] The quantities of toxic minerals (As, Hg, Pb and Cd) accumulated in the seeds of both cultivars were lower than the maximum limits recommended by the Codex Alimentarius,[27] indicating that consumption of these seeds is safe for human health. At 50 DAFS the leaves of *L. siceraria* were still green; if used judiciously, these could serve as a source of nutrients for livestock.

Amino acid composition and biological value of proteins

The amino acid composition, digestibility, chemical score and PDCAAS are the key components indicating the

nutritional quality of edible proteins.[28] The best profile of amino acids and the highest biological value of proteins of the kernels of *L. siceraria* were observed at 30 DAFS and CPW in the round and oval berry cultivars respectively. With reference to the values recommended by the FAO/WHO,[17] proteins from the kernels of *L. siceraria* could be considered a good source of amino acids, with only lysine being limiting. Protein digestibility ranged from 83.3 to 84.3%, within the range (70-85%) of proteins having low digestibility.[17] However, an appropriate technological treatment can improve the digestibility. Heat treatment strongly reduces the trypsic inhibitors that inactivate proteolytic enzymes and thus facilitates enzyme accessibility.[28] The greatest values of protein bioavailability were observed at30DAFS (56.9%) and CPW (55.0%) in the round and oval berry cultivars respectively. The bioavailability of proteins from both cultivars was better than the 52% for groundnut indicated by the FAO/WHO.[17]

Physicochemical properties of oil and fatty acid composition

The saponification, acid, iodine and peroxide values indicated that oil from the seed kernels of *L. siceraria* could be used for food and industrial purposes, whatever the fruit maturation stage. Indeed, highly saponifiable oils have wide industrial applications. According to the recommendations of the Codex Alimentarius,[29] acid and peroxide values of foods should not exceed 4 mg KOH g^{-1} and 10meq O_2 kg^{-1} respectively. The oils extracted from the seed kernels of *L. siceraria* were more stable than groundnut oil after 15 h of storage.[30] High oxidative stability of oils under heating at 100°C makes them suitable for food and industrial applications.[23] The degree of unsaturation of the oils extracted from both cultivars was higher than that reported for *Citrullus lanatus*, the second most widely produced oilseed cucurbit in Africa.[31] The fatty acid presenting the highest content in the oil of *L. siceraria* was linoleic acid (ω-6). It reached 645.7 g kg^{-1} at CPW and 665.3 g kg^{-1} at 30 DAFS in the round and oval berry cultivars respectively, similar to that (666.0 g kg^{-1}) found in the seed kernel of pumpkin.[23]

CONCLUSION

The results of this study showed that there were considerable modifications during fruit maturation in the oilseed gourd *L. siceraria* and that chemical characterisation of the seed kernel is important for controlling the processes of maturation. The two cultivars of *L. siceraria* studied should be harvested at 50 DAFS owing to their high contents of proteins, lipids, energy and minerals at this stage. At 50 DAFS the leaves of *L. siceraria* were still green and could serve as a source of nutrients for livestock. However, to obtain the best amino acid com position and biological values of proteins, the round and oval berry cultivars should be harvested at 30 DAFS and CPW respectively. At these stages their proteins could be used as a supplement. The low digestibility of the proteins at this stage could be improved by appropriate technological treatment.

The oils from both cultivars should be explored further for their potential to improve the nutritional value of human diets.

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Table 3. *Contents of essential amino acids (g AA per 16 g N, calculated from crude protein content) in Lagenaria siceraria seed kernels and biological values of protein at different maturation stages*

Amino acid	Round berry (sample size *n* = 3)						Oval berry (sample size *n* = 3)						FAO[17] (g AA per 16gN)
	30 DAFS		50 DAFS		CPW		30 DAFS		50 DAFS		CPW		
	g AA per 16gN	CS	g AA per 16gN	CS	g AA per 16gN	CS	g AA per 16gN	CS	g AA per 16gN	CS	g AA per 16gN	CS	
Histidine	3.17	166.91	2.96	155.59	3.04	159.96	2.90	152.72	2.89	151.92	3.48	183.42	1.9
Isoleucine	4.12	147.24	3.79	135.38	3.89	138.77	3.61	128.79	3.67	131.21	4.37	156.22	2.8
Leucine	6.37	96.59	5.83	88.38	6.03	91.40	5.58	84.48	5.66	85.69	6.73	102.00	6.6
Lysine	3.94	67.86	3.28	56.55	3.40	58.64	3.52	60.74	3.27	56.32	3.83	65.97	5.8
Methionine + cystine	4.20	168.16	3.70	147.88	3.77	150.81	3.57	142.73	3.78	151.37	4.25	170.20	2.5
Phenylalanine + tyrosine	8.16	129.59	7.58	120.33	7.77	123.23	7.15	113.52	7.29	115.75	8.87	140.75	6.3
Threonine	3.37	99.25	3.07	90.33	3.22	94.82	2.99	88.01	2.98	87.54	3.64	106.93	3.4
Tryptophane	1.86	169.29	2.03	184.39	1.79	162.28	1.70	154.27	1.66	150.67	2.09	189.80	1.1
Valine	5.17	147.76	4.57	130.50	4.74	135.42	4.54	129.66	4.49	128.25	5.26	150.37	3.5
Chemical score (%)	67.86		56.55		58.64		60.74		56.32		65.97		-
Limiting amino acid	Lysine		Lysine		Lysine		Lysine		Lysine		Lysine		-
Digestibility[a]	83.9 ± 0.0a		83.3 ± 0.2b		83.4 ± 0.0b		84.3 ± 0.1a		83.3 ± 0.2b		83.3 ± 0.1b		-
PDCAAS[a]	56.9 ± 0.0a		47.1 ± 0.1b		48.9 ± 0.0b		51.2 ± 0.1b		46.9 ± 0.1b		55.0 ± 0.1a		-

CS, chemical score; PDCAAS, protein digestibility-corrected amino acid score.
[a] For digestibility and PDCAAS, mean values followed by 'a' were the higher averages and mean values followed by 'b' were the lower averages based on the Gupta test at 0.05 level.

Table 4. *Physicochemical properties of Lagenaria siceraria seed kernel oils at different maturation stages*

	Round berry (sample size *n* = 3)			Oval berry (sample size *n* = 3)		
Property[a]	**30 DAFS**	**50 DAFS**	**CPW**	**30 DAFS**	**50 DAFS**	**CPW**
Acid value (mg KOH g^{-1} oil)	2.30 ± 0.05a	1.14 ± 0.28b	0.47 ± 0.03b	0.53 ± 0.00b	0.57 ± 0.00a	0.40 ± 0.00b
Iodine value (g per 100 g oil)	117.65 ± 0.51b	121.68 ± 0.23b	123.07 ± 0.39a	124.36 ± 0.72a	122.89 ± 0.45a	118.03 ± 0.29b
Saponifkation value (mg KOH g^{-1} oil)	194.50 ± 0.71	193.81 ± 0.20	193.97 ± 0.55	194.13 ± 0.85	193.89 ± 0.60	194.00 ± 0.47
Peroxide value (meq O2 kg^{-1} oil)	6.70 ± 0.20a	4.72 ± 0.05b	2.55 ± 0.24b	3.67 ± 0.10	5.81 ± 0.73	4.64 ± 0.42
Unsaponifiable matter (g kg^{-1})	1.1 ± 0.0	3.8 ± 0.1	6.7 ± 2.8	12.1 ± 2.1	11.4 ± 0.2	17.7 ± 6.0
Colour (Gardner units)	5.00 ± 0.00a	4.00 ± 0.00b	3.00 ± 0.00b	5.00 ± 0.00a	5.00 ± 0.00a	3.00 ± 0.00b
Induction time (h)	19.55 ± 0.21a	19.75 ± 0.07a	15.45 ± 0.07b	31.18 ± 0.88a	20.90 ± 0.28b	19.35 ± 2.62b

[a] For each property, mean values followed by 'a' were the higher averages and mean values followed by 'b' were the lower averages based on the Gupta test at 0.05 level; mean values without letters were not significantly different ($P > 0.05$).

Table 5. *Fatty acid profile (g kg^{-1} dry matter) of Lagenaria siceraria seed kernel oils at different maturation stages*

	Round berry (sample size *n* = 4)			Oval berry (sample size *n* = 4)		
Fatty acid[a]	**30 DAFS**	**50 DAFS**	**CPW**	**30 DAFS**	**50 DAFS**	**CPW**
Saturated fatty acids (SFAs)						
Myristic	1.2 ± 0.1a	0.8 ± 0.0b	1.0 ± 0.1a	1.0 ± 0.1	0.8 ± 0.1	0.7 ± 0.1
Palmitic	164.4 ± 0.4a	135.7 ± 0.3b	141.3 ± 0.4b	148.9 ± 0.1a	137.7 ± 0.8b	127.0 ± 1.1b
Heptadecanoic	0.9 ± 0.0a	0.0 ± 0.0b	0.8 ± 0.0b	0.9 ± 0.0a	0.7 ± 0.0b	0.7 ± 0.0b
Stearic	83.1 ± 0.1a	75.1 ± 0.0b	77.6 ± 0.2b	75.4 ± 0.1a	64.6 ± 0.0b	62.9 ± 0.1b
Arachidic	4.8 ± 0.1a	3.8 ± 0.0b	3.6 ± 0.1b	3.5 ± 0.0a	3.2 ± 0.0b	3.4 ± 0.0b
Lignoceric	1.5 ± 0.0a	1.3 ± 0.0b	1.2 ± 0.0b	1.3 ± 0.0a	1.2 ± 0.0b	1.2 ± 0.0b
Total SFAs	252.2 ± 0.6a	214.6 ± 0.3b	222.4 ± 0.5b	227.8 ± 0.2a	205.5 ± 0.8b	193.3 ± 1.1b
Monounsaturated fatty acids (MUFAs)						
Palmitoleic	0.9 ± 0.0a	0.7 ± 0.0b	0.7 ± 0.0b	0.8 ± 0.0a	0.7 ± 0.0b	0.8 ± 0.0a
Oleic	127.7 ± 0.4b	157.9 ± 0.1a	126.2 ± 0.4b	101.0 ± 0.4b	161.9 ± 0.3b	236.4 ± 0.3a
Eicosenoic	0.0 ± 0.0b	1.2 ± 0.1a	1.3 ± 0.1a	1.0 ± 0.0b	1.2 ± 0.0b	1.5 ± 0.0a
Total MUFAs	127.7 ± 0.4b	159.0 ± 0.1a	127.5 ± 0.4a	101.0 ± 0.4b	163.1 ± 0.3b	237.9 ± 0.3a
Polyunsaturated fatty acids (PUFAs)						
Linoleic	612.6 ± 2.8b	621.9 ± 1.3b	645.7 ± 2.1a	665.3 ± 4.0a	627.1 ± 2.8b	564.1 ± 1.8b
Linolenic	2.2 ± 0.0a	1.5 ± 0.0b	1.5 ± 0.0b	1.7 ± 0.0a	1.4 ± 0.0b	0.8 ± 0.0b
Total PUFAs	614.8 ± 2.8b	623.4 ± 1.3b	647.2 ± 2.1a	667.0 ± 4.0a	628.5 ± 2.8b	564.1 ± 1.8b

[a] For each fatty acid, mean values followed by 'a' were the higher averages and mean values followed by 'b' were the lower averages based on the Gupta test at 0.05 level; mean values without letters were not significantly different ($P > 0.05$).

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