

Nutritional value and fatty acid profile of niger (*Guizotia abyssinica*) plant during its growth cycle

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Abstract

The nutritional value and fatty acid profile of the *Guizotia abyssinica* plant harvested for forage at seven growth stages were determined.

Generally, growth stage resulted in an increase in neutral detergent fibre (NDF), acid detergent fibre, lignin, and indigestible NDF and a decrease in protein content, *in vitro* true digestibility and NDF digestibility. Among the main fatty acids (FA) in the plant during growth, α -linolenic acid (C_{18:3 n-3}) and linoleic acid (C_{18:2 n-6}) were the most abundant (from 440 to 548 and from 154 to 195 g/kg of total FA, respectively). Some minor FAs showed no differences in their content during growth. The whole plant was characterised by a high proportion of polyunsaturated fatty acids, which made up between 696 and 764 g/kg of total FA, and a low proportion of saturated fatty acids.

Niger is a forage plant with a good nutritional value and an interesting FA profile and should be harvested no later than the shooting stage of growth to ensure that the forage has high nutritive value and maintains a moderately high nutrient digestibility.

Key words: *crude protein, digestibility, fibrous fractions, gross energy, lipid, Noug*

Introduction

Niger (*Guizotia abyssinica* Cass) belongs to the family *Compositae* and the genus *Guizotia*, which has only six species, of which five are native to Ethiopia (Baagøe 1974). *Guizotia abyssinica* is the only species (with a number of varieties) cultivated in different countries throughout tropical and temperate zones. Ethiopia and India are the chief niger producing countries of the world, but this annual herbaceous plant is also extensively cultivated in Sudan, Uganda, Zaire, Tanzania, Malawi, Zimbabwe, the West Indies, Nepal, Bangladesh, and Bhutan (Weiss 1983). Niger is an oilseed crop of commercial importance (Bhagya and Shamanthaka Sastry 2003) because its seed contains about 40% oil with a fatty acid (FA) composition of 75-80% linoleic acid (LA, C_{18:2 n-6}) (Getinet and Tekelewold 1995). In Europe and North America, niger seed is used as a birdseed. It is also used as a human food and today is particularly important to the economy of Ethiopia, where it accounts for 50-60% of its edible oil supply. Its oil is also used in the manufacture of soaps and paints and as a

lubricant or lighting fuel (Shahidi et al 2003).

The meal remaining after oil extraction is free from any toxic substance and contains approximately 30% protein and 23% crude fibre (Getinet and Sharma 1996). It is used as feed, fertilizer or fuel. In particular, in tropical regions, with their poor quality of basal feed and lack of supplementation with locally available energy and protein sources, niger seed meal is an important supplement for sheep (Nega and Melaku 2009) and goats (Alemu et al 2010). Nega and Melaku (2009) demonstrated that supplementation of hay with niger seed meal improved dry matter (DM) intake, apparent digestibility coefficient and body weight performance of Farta sheep, presumably due to better availability and increased utilization of nutrients. Nawanyakpa et al (1986) determined the effect of feeding teff straw and molasses-urea with and without niger cake on sheep growth rate, feed intake and nutrient utilization. They found that DM and N digestibilities were higher in sheep fed niger cake than in those deprived of the meal. Butterworth and Mosi (1985) analyzed intake and digestibility by sheep of oat straw and maize stover fed with different levels of niger meal and found a strong positive relationship between increasing N intake and cellulose digestibility, intake of low quality roughage and bodyweight gain in young animals.

Sinha et al (1983) replaced linseed cake with niger cake at levels of 0, 50 and 100% as a nitrogen supplement for growing calves. They concluded that niger cake can replace linseed cake in calf rations because they found no significant differences in feed efficiency, growth rate and DM digestibility between animals fed with niger and those fed linseed cake. Similarly Roychoudhury and Mandal (1984) reported no significant difference in weight gain of large White Yorkshire pigs fed rations containing either niger cake or groundnut cake.

There is limited information on the feeding value of the niger plant, which is consumed by sheep but not by cattle, to which only niger silage can be fed (Chavan 1961). Unfortunately, the lack of information on the nutritive value of most of the forage resources used in tropical areas in general can lead to unbalanced diets, low animal growth and reproduction performance, low income for farmers and less locally produced animal protein available on the market (Kambashi et al 2014).

The objective of this experiment was to assess the changes in the chemical composition, *in vitro* true digestibility (IVTD), neutral detergent fibre digestibility (NDFD), indigestible neutral detergent fibre (INDF), gross energy (GE) and FA profiles of the niger plant at seven stages of development.

Materials and methods

Plant material and environmental conditions

The study was conducted in the Western Po Valley near Cuneo, Italy (44° 41' N, 7° 11' E). The climate is characterised by high precipitation in spring and autumn (96-110 mm/month) with little rainfall in summer and winter. The mean daily temperatures increase from 0.5°C in January to 22°C by the end of July. Niger seeds were obtained from the Ornitalia Product Service s.a.s. (Colleredo di Monte Albano (UD), Italy). The stands were seeded on 24 April 2013 and no irrigation or fertilizers were applied after sowing. The herbage samples were collected with edging shears (0.1 m cutting width) from 1 m² subplots randomly located in 2

x 7 m² plots with two replicates at seven progressive morphological stages from early vegetative to grain fill from July to September 2013. Plants were cut to a 1-2 cm stubble height and sampling was performed in the morning after the disappearance of dew and was not carried out on rainy days.

Chemical analysis

The herbage samples were immediately dried in a forced-draft air oven to a constant weight of 65°C, brought to air temperature, weighed, ground in a Cyclotec mill (Tecator, Herndon, VA, USA) to pass through a 1 mm screen and stored for qualitative analysis.

Dried herbage samples were analyzed to determine the total N content (AOAC 1990) and ash by ignition to 550°C. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were determined with the Ankom²⁰⁰ Fibre Analyzer (Ankom Technology Corp., Fairport, NY, USA), following the procedure of Van Soest et al (1991) and corrected for residual ash content. The NDF was analyzed without sodium sulfite and α -amylase, as described by Van Soest et al (1991).

The herbage samples were also analyzed to determine IVTD, NDFD and INDF, using the Daisy^{II} Incubator (Ankom, Tech. Co., Fairport, NY, USA), according to Robinson et al (1999). The *in vitro* rumen incubations were performed in two consecutive fermentative runs. Ground samples (size of grind, 250 mg) were inserted into filter bags (Ankom F57 bags) which were then sealed. Digestion jars were filled with pre-warmed (39°C) buffer solutions (266 ml of solution A: KH₂PO₄ 10 g/l, MgSO₄·7H₂O 0.5 g/l, NaCl 0.5 g/l, CaCl₂·2H₂O 0.1 g/l, Urea 0.5 g/l; 1330 ml of solution B: Na₂CO₃ 15.0 g/l, Na₂S·9H₂O 1.0 g/l) and placed into the Daisy^{II} Incubator. Rumen liquor was collected from rumen contents obtained at a slaughterhouse and 400 ml of liquor filtered through two layers of cheesecloth was introduced into each jar together with the filter bags. After 48 h incubation, the bags were removed, rinsed thoroughly with cold tap water and immediately analyzed for NDF content with the Ankom²⁰⁰ Fibre Analyzer and incinerated to correct the residual NDF for the residual ash.

IVTD was calculated as follows:

$$\text{IVTD} = 1000 - (W_3 - (W_1 \times C_1)) \times 1000 / (W_2 \times \text{DM} / 100)$$

where W_1 is the filter bag weight, W_2 is sample weight, W_3 is the final weight (filter bag+residue) after *in vitro* digestion, C_1 is the comparative weight of the filter bag after and before digestion treatment and DM is the DM content of the samples.

NDFD was calculated using the following equation:

$$\text{NDFD} = 1000 - (W_3 - (W_1 * C_1)) * 1000 / (W_2 * \text{NDF})$$

where W_1 is the filter bag weight, W_2 is the sample weight, W_3 is the final weight (filter bag+residue) after *in vitro* and sequential treatment with NDF solution, C_1 is a comparison of the blank filter bag weight after and before digestion treatment and NDF is neutral detergent fibre content of the sample.

INDF was calculated using the following equation:

$$\text{INDF} = \text{NDF} - \text{dNDF}$$

where NDF was neutral detergent fibre content of the sample and dNDF was digestible neutral detergent fibre ($\text{NDF} * \text{NDFD} / 1000$).

Fatty acid analysis

Fresh samples (200 g) of the herbage were refrigerated, freeze-dried and ground to pass through a 1 mm screen. Lipid extraction was performed on freeze-dried samples according to Hara and Radin (1978), while transesterification of the FAs was performed according to Christie (1982), with the modifications described by Chouinard et al (1999). The FA methyl esters were then determined by gas chromatography according to Peiretti and Meineri (2008).

Statistical analysis

The variability in the FA and herbage quality characteristics harvested at seven different stages of maturity was analyzed for statistical significance via analysis of variance (ANOVA) using the Statistical Package for Social Science (SPSS Inc 2002) to test the effect of the growth stage. When the values of F were significant (i.e., $P < 0.05$), the Duncan range test (Duncan 1955) was used to detect differences among means. The data were regressed on days after sowing as independent variable.

Results and discussion

Crop quality and *in vitro* digestibility

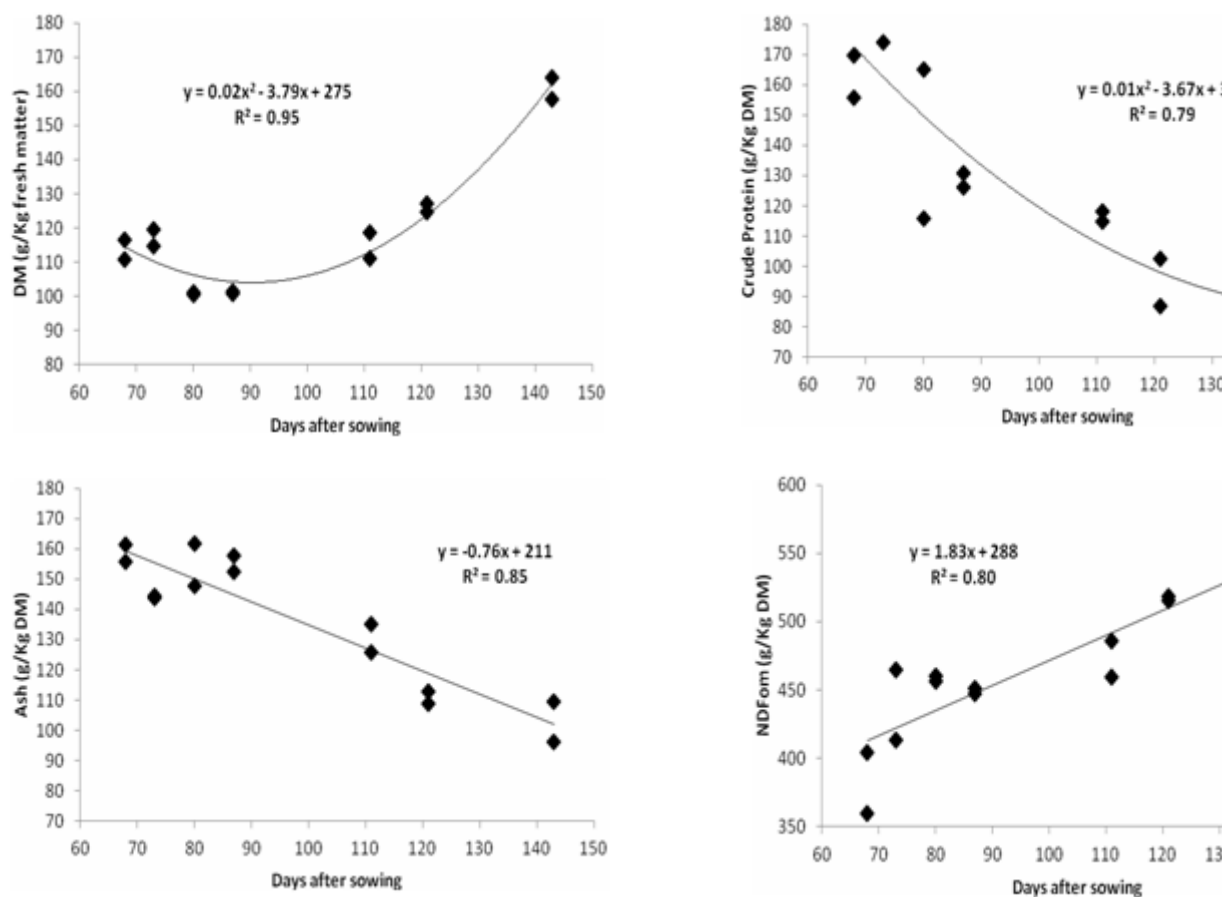
The evolution of niger plant quality at the seven different stages of development is reported in Table 1. Generally, growth stage resulted in an increase in fibre content and decrease in CP, ash and digestibility. There were no substantial changes in lipid content during plant maturity.

Table 1. Chemical composition (g/kg DM), gross energy (GE), *in vitro* true digestibility (IVTD), neutral detergent fibre digestible neutral detergent fibre (INDF) of *Guizotia abyssinica* at seven morphological stages

Stage	Early vegetative	Mid vegetative	Late vegetative	Shooting	Budding	Early flower	Grain fill
Days after sowing	68	73	80	87	111	121	143
DM, g/kg FM	114 ^b	117 ^b	101 ^a	101 ^a	115 ^b	126 ^c	161 ^d
Crude protein	163 ^{de}	186 ^e	140 ^{cd}	128 ^{bcd}	116 ^{abc}	94.6 ^{ab}	86.0 ^a
Lipid	11.5	14.8	10.3	12.0	12.9	12.8	11.4
Ash	158 ^c	144 ^{bc}	155 ^c	155 ^c	130 ^b	111 ^a	103 ^a
NDF	382 ^a	439 ^b	458 ^b	449 ^b	473 ^{bc}	517 ^{cd}	551 ^d
ADF	234 ^a	277 ^b	287 ^b	291 ^b	307 ^{bc}	346 ^{cd}	353 ^d
Lignin	43.7 ^a	55.8 ^b	58.3 ^{bc}	59.0 ^{bc}	59.0 ^{bc}	59.4 ^{bc}	63.8 ^c
GE, MJ/kg DM	16.3 ^{bc}	16.5 ^{cd}	15.8 ^a	15.9 ^{ab}	16.4 ^c	16.5 ^{cd}	16.9 ^d
IVTD, g/kg DM	943 ^a	929 ^{ab}	908 ^{ab}	882 ^{bc}	836 ^c	776 ^d	782 ^d
NDFD, g/kg NDF	851 ^a	839 ^a	800 ^{ab}	738 ^{ab}	654 ^c	567 ^{cd}	606 ^d
INDF, g/kg NDF	56.7 ^a	71.4 ^{ab}	91.6 ^{ab}	117.6 ^{bc}	163.7 ^c	223.9 ^d	217.8 ^d

As regards CP content, it decreased respectively from 163 to 86.0 g/kg DM from the early vegetative through to the grain fill stage. A similar trend, but with lower values, was observed in a study carried out on ravizzone plant samples collected from the vegetative through to the ripening stage (Peiretti et al 2012).

All fibre component contents increased with maturity ($P < 0.05$). The concentration of NDF and ADF increased respectively from 381.7 to 550.7 g/kg DM and from 233.7 to 352.6 g/kg DM from the early vegetative to the grain fill stage. Their trend was similar (Figure 1). NDF and ADF concentration increased significantly between the early to mid vegetative stages; no differences appeared between the mid and late vegetative, shooting and budding stages; similar content was found in the early flowering and grain fill stages. In agreement with Coblenz et al (2013), we found a positive relationships between NDF and plant maturity. Mature plants were generally taller than vegetative plants and thus have a greater proportion of stem relative to leaf tissue.



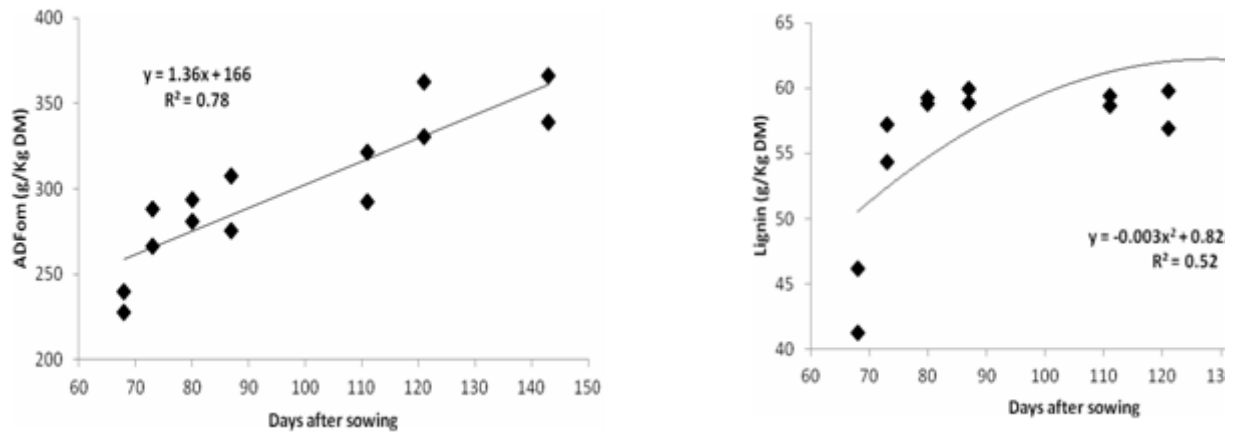


Figure 1. Chemical composition in *Guizotia abyssinica* as a function of age in days after sowing

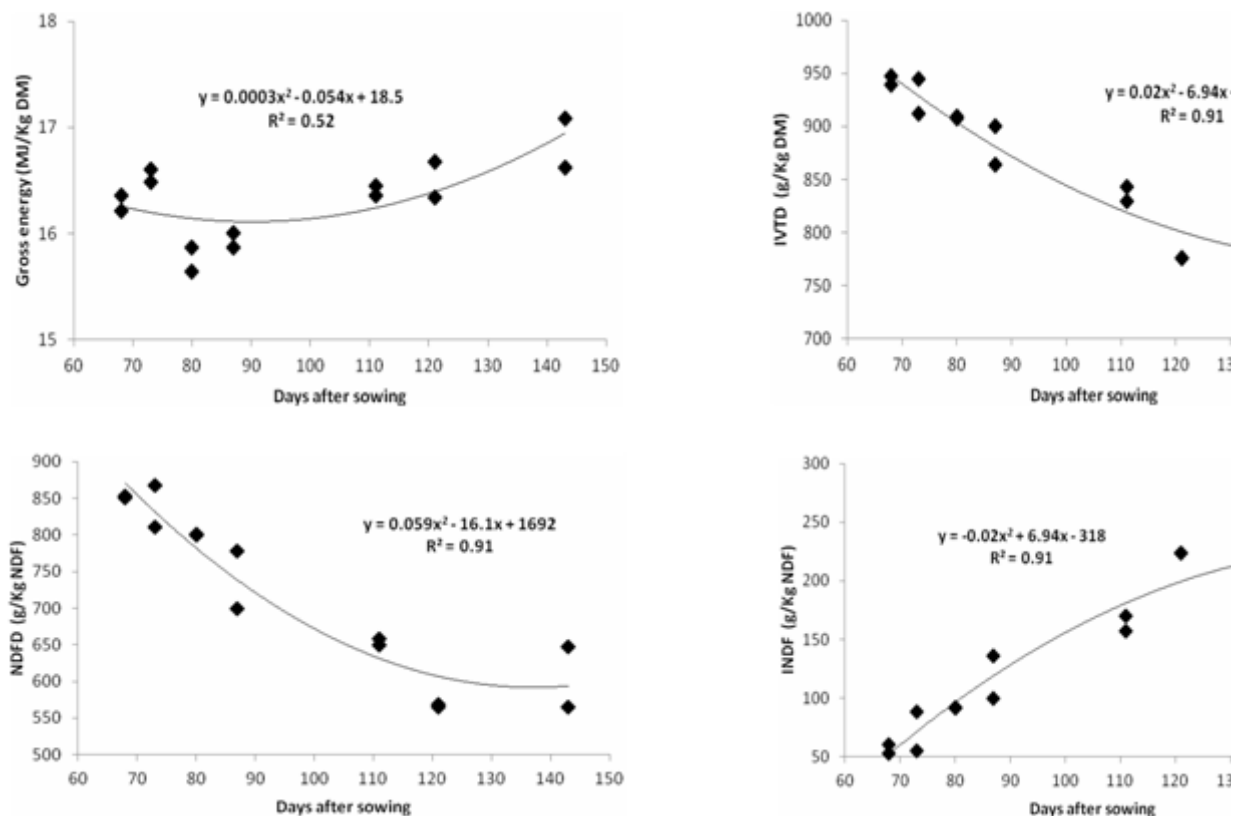


Figure 2. Gross energy, *in vitro* true digestibility (IVTD), neutral detergent fibre digestibility, and indigestible detergent fibre (INDF) in *Guizotia abyssinica* as a function of age in days after sowing

Lignification increased from 43.7 to 63.8 g/kg during maturity. Values were similar between mid vegetative to early flowering stages (55.8-59.4 g/kg DM). It is reasonable to suspect that niger plant grown during summer should be lignified more extensively than comparable plants maturing during fall. Indeed, Van Soest (1982) found for many forages that there is a positive relationship between temperature and lignification.

The results of the *in vitro* digestion trial indicate that niger plant was highly digestible in vegetative stages (IVTD >900 g/kg DM), as were its cell walls, which are quantified as neutral detergent fibre (NDFD ≥800 g/kg NDF). IVTD and NDFD decreased significantly with maturity, but did not exceed respectively 782.2 g/kg DM and 606 g/kg NDF at the grain fill stage (Figure 2).

The decrease in digestibility probably reflects concomitant increases in lignification of the

crop. In fact, as demonstrated by Coblenz et al (2013), NDFD was inversely related to growth stage and was closely associated with concentrations of lignin. Deinum (1984) observed that the decline in digestibility with increased maturity was dependent on temperature.

A similar trend was observed for INDF, ranging from 56.7 g/kg in the early vegetative stage to 217.8 at the grain fill stage. An increase in INDF at the increased maturity stage has also been observed by others (Nordheim-Viken et al 2009; Nordheim-Viken and Volden 2008). Nordheim et al (2009) found a strong positive relationship between indigestible fibre fraction and lignin in timothy, in agreement with Allen and Mertens (1988). Moreover, the authors showed that the maturity stage was the only factor affecting INDF content, with a decrease in leaf:stem ratio and an increase in INDF in the stem fraction. Ellis et al (1999) reported that INDF played a dominant role in forage utilization and emphasized the importance of including this entity in feed evaluation.

Age in days after sowing (Figures 1 and 2) was a good predictor of DM content, IVTD, NDFD, and INDF of niger plant ($R^2 > 0.91$).

Stage of growth seems to be the most important factor affecting the chemical composition and digestibility of forage. Significantly, differences exist in changes in nutrient quality associated with increased maturity in niger plant, as in other tropical forages (Arthington and Brown 2005). Forage was highly succulent in early growth, which markedly enhances its palatability. In addition, its high protein content in relation to a low fibre content at this stage makes it highly nutritious as livestock forage, in particular in the tropics, where the basal feed is of poor quality (CP content of hays below 5%) and supplementation with locally available energy and protein sources is lacking (Deneke 2005). The trend in fibre content, compared to stage of maturity, is the reverse of protein. As the percentage of fibre increases, digestibility decreases because lignification makes it unavailable. The digestibility of niger plant, like temperate grasses (Huhtanen et al 2006), varied with the concentration and digestibility of cell walls. Compared with temperate forages, tropical forages typically have higher annual DM yield and consequently less qualitative value. However, niger plant maintained a high nutritive value and digestibility throughout growth.

Fatty acid profile

The FA profile in the plant during growth is reported in Table 2.

Table 2. Fatty acid composition (g/kg of total FA) of *Guizotia abyssinica* at seven morphological stages

Stage	Early vegetative	Mid vegetative	Late vegetative	Shooting	Budding	Early flower	Grain fill	SEM
Days after sowing	68	73	80	87	111	121	143	
C _{16:0}	96.0 ^a	106 ^{ab}	119 ^{cd}	121 ^d	103 ^{ab}	109 ^{bc}	100 ^{ab}	2.53
C _{17:0}	4.15 ^c	2.85 ^b	3.10 ^b	2.45 ^{ab}	2.10 ^a	2.00 ^a	1.80 ^a	0.22
C _{18:0}	13.0	19.0	18.5	20.0	18.0	16.5	26.5	1.33
C _{18:1n-9}	16.5 ^{ab}	30.5 ^{cd}	28.0 ^{bcd}	27.5 ^{bcd}	19.0 ^{abc}	15.3 ^a	37.5 ^d	2.34
C _{18:1n-7}	n.d. [#]	5.50 ^{bc}	4.95 ^{bc}	3.50 ^{abc}	4.10 ^{bc}	3.20 ^{ab}	7.45 ^c	0.68
C _{18:2n-6}	172 ^{abc}	168 ^{abc}	183 ^{cd}	194 ^d	160 ^{ab}	180 ^{bcd}	154 ^a	3.90
C _{18:3n-6}	34.5	40.0	33.0	42.5	39.5	26.0	29.5	2.93
C _{18:3n-3}	548 ^c	503 ^{bc}	463 ^{ab}	440 ^a	494 ^b	505 ^{bc}	505 ^{bc}	9.69
C _{20:2}	9.60 ^a	11.5 ^a	18.5 ^b	19.5 ^b	17.5 ^b	19.0 ^b	19.5 ^b	1.15
C _{22:0}	5.40	5.00	5.95	7.40	5.45	6.05	5.70	0.30

C _{24:0}	8.75	9.65	10.5	13.0	10.0	11.0	8.25	0.49
Others	91.5	99.0	112	108	126	108	105	3.14

abc Within a row, values with different letters differ

Not detected

Among main FAs of the plant during growth, α -linolenic acid (ALA, C_{18:3 n-3}) and linoleic acid (C_{18:2 n-6}) were the most abundant (from 440 to 548 and from 154 to 195 g/kg of total FA, respectively). Some minor FAs (C_{18:0}, C_{18:3 n-6}, C_{22:0} and C_{24:0}) did not show differences in their content during growth. The whole plant was characterised by a high proportion of polyunsaturated FAs, which made up from 696 to 764 g/kg of total FA, while there was a low proportion of palmitic acid (C_{16:0}) and other saturated FAs. ALA was the most abundant FA during the entire growth cycle investigated, as has also been reported for other oilseed crops such as false flax (Peiretti and Meineri 2007), golden flax (Peiretti and Meineri 2008) and chia (Peiretti and Gai 2009).

Age in days after sowing was unable to predict the changes in the fatty acid composition with low R² (Figure 3).

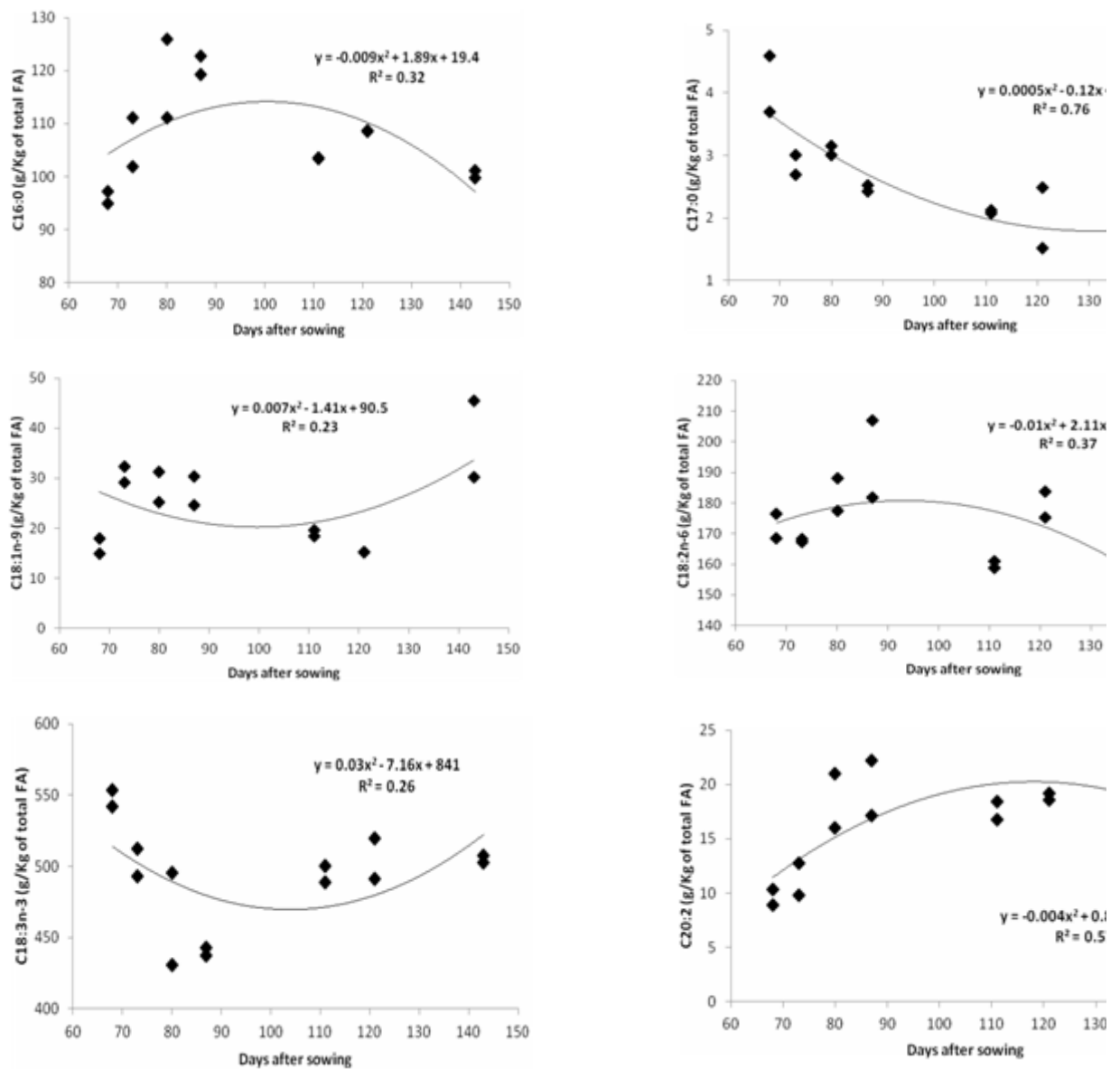


Figure 3. Fatty acid (FA) in *Guizotia abyssinica* as a function of age in days after sowing

Conclusions

- *Guizotia abyssinica* could be a good forage resource both in tropical and in temperate environments with a good FA profile.
- It could be suggested that niger should be harvested for forage production no later than the shooting stage of growth, to ensure that the forage has high nutritional value and maintains moderately high digestibility of nutrients.

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