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Effect of the inclusion of *Amaranthus dubius* in diets on carcass characteristics and meat quality of fattening rabbits

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ABSTRACT

This study evaluated the effect of dietary supplementation with *Amaranthus dubius* on carcass characteristics and meat quality of fattening rabbits. One hundred and six New Zealand White rabbits, weaned at 35 d of age, were assigned to three experimental diets including 0%, 16% and 32% of *A. dubius* (A0, A16 and A32), and were fed *ad libitum* until their slaughter at 87 d of age. Drip loss percentage (A0: 2.47, A16: 3.83 and A32: 3.61%; $P < .05$), dissectible fact percentage (A0: 3.02, A16: 3.63 and A32: 3.77%; $P < .05$) and thoracic cage percentage (A0: 12.97, A16: 13.68 and A32: 13.68%; $P < .05$) increased with diets including *A. dubius*. Contrarily, hind part percentage (A0: 40.00, A16: 38.95 and A32: 38.89%; $P < .05$) and compactness of the carcass decreased (A0: 2.38, A16: 2.42 and A32: 2.48; $P < .01$). The inclusion of *A. dubius* in the diets increased protein (A0: 21.52, A16: 23.76 and A32: 24.27%; $P < .05$) and fat contents (A0: 3.33, A16: 4.16 and A32: 5.39%; $P < .05$), while moisture of meat decreased proportionally (A0: 74.23, A16: 70.99 and A32: 67.70%; $P < .05$). These findings suggest that *A. dubius* can be considered as an alternative raw material for rabbit feeding in tropical and subtropical regions where it is widespread.

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Amaranth; alternative feed resources; feeding; tropical and subtropical conditions

1. Introduction

Carcass characteristics and meat quality are the fundamental aspects that guide research on the production of fattening rabbits, due to the relevance reached by this species to produce meat of good nutritional quality (Dalle Zotte 2002; Dal Bosco et al. 2012; Capra et al. 2013) with high reproductive and growing performance (Strychalski et al. 2014). Rabbit meat has several attributes that make it superior to that of other species, mainly its higher protein and lower fat contents (Dalle Zotte 2002).

In tropical and subtropical countries, one of the main constraints to the production of meat rabbits is the high cost of commercial feed, due to the low availability of raw materials in the market because most of them are imported products, and due to the fact that several of these products are necessary for humans (Oseni & Lukefahr 2014). These balanced feeds are usually manufactured with raw materials such as alfalfa, soy and corn, among others, which can be substituted in nutritional and agronomic terms by others better adapted to tropical and subtropical environments and that are not required for human consumption (Nieves et al. 2008). A key aspect is to use plants or vegetable sources in rabbit feeding, especially forage, since the rabbit is a herbivorous monogastric species (Akoutey et al. 2012). In this context, research on rabbit feeding is focused on the development of new products of high nutritional quality, by using unconventional raw materials and new technologies, allowing a significant increase in production and a decrease in costs (Guemour et al. 2010; Bhatt et al. 2017).

Amaranth is a plant belonging to the Amarantaceae family, genus *Amaranthus*, with more than 60 species distributed in tropical and subtropical regions. Due to the excellent nutrient composition of some amaranth species, they have become relevant in human and animal nutrition (Montero-Quintero et al. 2011; Molina et al. 2015). *Amaranthus dubius* is highly distributed in all regions of Venezuela and other tropical and subtropical American countries, where it is considered as a weed of various subsistence crops, such as corn, sorghum and several legumes (Olivares & Peña 2009). It is also locally naturalized in Europe, Asia and Africa. It presents a high yield of green matter, as well as an excellent nutrient content (Arellano et al. 2004; Montero-Quintero et al. 2011); however, this is a species unexploited as a crop, while its seeds are eaten as a cereal and the leaves and stems as a vegetable (Matteucci et al. 1999). Amaranth species have been used for feeding rabbits (Bamikole et al. 2000; Bautista & Barrueta 2000; Molina et al. 2015). However, there are no reports of its effects on carcass characteristics and meat quality of growing rabbits. The objective of the present research was to study the effects of diets formulated with the inclusion of 16% and 32% of *A. dubius* Mart. ex Thell. flour on the carcass characteristics and meat quality of fattening rabbits.

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2. Material and methods

This study was carried out according to the guidelines of the European Group on Rabbit Nutrition for applied nutrition experiments in rabbits (Fernández-Carmona et al. 2005) and complies with the Council of the European Communities (1986) recommendations on the care and protection of animals used for experimental purposes.

2.1. Feed formulation and manufacturing

Mature *A. dubius* plants, including leaves, stems and panicles, were collected manually during the rainy season (September to November) in an experimental plantation located in the Zulia state, Venezuela. Samples were harvested approximately 80 d after seeding and subjected to oven-drying (between 50 and 60°C for 40 h in a self-built room oven). Subsequently, the dried samples were ground and sieved at 0.5 mm (Resh Muhle Dietz, LB1-27), and the flour was placed in hermetically closed plastic containers, which were stored at room temperature (approximately 25°C) and well ventilated until its analysis and utilization as raw material in the manufacture of pelleted diets.

A basal mixture (control diet; A0) which contained corn, soybean, wheat bran, Guinea grass (*Panicum maximum*), palm kernel, soybean oil and cane molasses as main ingredients was formulated to fit the nutritional requirement of growing rabbits (De Blas & Mateos 2010). Two additional experimental diets were prepared by partial substitution of corn, wheat bran, Guinea grass (*P. maximum*) and cane molasses in control diet with 16% or 32% of *A. dubius* (A16 and A32 diets, respectively), while soybean oil was increased. Soybean and palm kernel contents were adjusted in A16 and A32 diets to balance them. Salt, mineral–vitamins premix and sepiolite (binder) were added to all diets in constant proportions. The ingredients and chemical composition of the three diets are shown in Table 1. The diets were formulated to have similar levels of crude protein (CP) and digestible energy (DE). The diets were pelleted (3 mm in diameter and 5–10 mm in length) using a meat mill to which was adapted a special disc, and were subsequently baked (180°C for 30 min). The dry matter (DM), ether extract (EE), crude fibre (CF), acid detergent fibre (ADF), ash and CP were analysed in experimental diets and *A. dubius* flour by the procedures of Association of Official Analytical Chemists (AOAC 2005). The neutral detergent fibre (NDF) was analysed with a heat-stable amylase and expressed inclusive of residual ash, without sodium sulphite (Mertens 2002). Acid detergent lignin (ADL) was determined according to Van Soest et al. (1991). Three replicates per treatment were analysed.

Table 1. Ingredients and chemical composition of the experimental diets.

	Experimental diets[a]		
	A0	A16	A32
Ingredient, % (as-fed basis)			
A. dubius	0.00	16.00	32.00
Corn	9.60	6.04	3.06
Soybean	11.06	9.50	10.70
Wheat bran	40.60	34.98	24.33
Panicum maximum Straw	16.32	4.77	1.19
Palm kernel	11.90	15.40	11.06
Soybean oil	1.28	6.31	12.46
Cane molasses	5.74	3.50	1.70
Sodium chloride	1.00	1.00	1.00
Sepiolite[b]	1.50	1.50	1.50
Vitamin–mineral premix[c]	1.00	1.00	1.00
Chemical composition, % (DM basis)[d]			
Dry matter (DM)	90.92	89.28	91.70
Crude protein (CP)	15.90	15.39	15.07
Ether extract (EE)	0.20	0.36	0.46
Ash	7.06	7.12	7.27
Crude fibre (CF)	15.73	14.90	16.17
Neutral detergent fibre (NDF)	34.68	33.72	30.70
Acid detergent fibre (ADF)	20.42	20.28	23.42
Acid detergent lignin (ADL)	10.10	12.05	9.02
Digestible energy[e] (DE, MJ/kg DM)	12.27	12.35	12.11

[a]A0, A16 and A32 diets include 0%, 16% and 32% of *A. dubius*.
[b]Exal H®; provided by TOLSA GROUP (Madrid, Spain).
[c]Tecnovit Conejos Único®; provided by Tecnología and Vitaminas, S.L. (Tarragona, Spain). Mineral and vitamins composition (g/100 g premix): Fe: 1.00, I: 0.02, Co: 0.002, Cu: 0.3, Mn: 1.00, Zn: 1.20, Se: 0.002, Vitamin E: 0.32, Vitamin B_1: 0.02, Vitamin B_2: 0.06, Vitamin B_6: 0.02, Vitamin B_{12}: 0.0002, Calcium d-pantothenate: 0.20, Nicotinic acid: 0.44, Choline chloride: 1.00, Robenidine hydrochloride: 1.32, Vitamin A: 180,000 IU, Vitamin D_3: 30,000 IU.
[d]Samples were chemically analysed ($n = 3$ replicates per treatment).
[e]DE was calculated according to Fekete and Gippert (1986) as: DE (kcal/kg DM) = 4253–32.6 × Crude fibre (% DM) − 144.4 × Ash (% DM); it was subsequently transformed to MJ/kg DM.

2.2. Animals and housing conditions

Experimental animals, obtained from a purebred New Zealand White stock of the farm of the National Institute of Hygiene 'Rafael Rangel' (Moya et al. 2006), came from a growing performance and digestibility trial (Molina et al. 2015) in which 106 rabbits weaned at 35 d (mean weight ± SD: 760 ± 102 g), balanced by sexes, were randomly assigned to one of the three experimental diets until slaughtering (A0: $n = 36$, A16: $n = 35$, A32: $n = 35$). The animals were housed in individual wire mesh cages measuring 50 × 25 × 40 cm (length, width and height). The farm was an open-air building equipped with fans to circulate the air, with a natural lighting regime. The temperature and relative humidity during the test ranged 23–32°C and 50–80%, respectively, and corresponded to tropical conditions. Rabbits were given *ad libitum* access to water and feed throughout the trial.

2.3. Carcass characteristics

At 87 d of age, the rabbits were slaughtered (mean live weight ± SD: 1,883 ± 183 g) and carcasses were prepared as recommended by the World Rabbit Science Association (Blasco & Ouhayoun 1996). The slaughtered rabbits were bled and then the skin, genitals, urinary bladder, gastrointestinal tract and distal parts of legs were removed. Hot carcasses were suspended in a ventilated area for 30 min and weighed, and were subsequently chilled at 4°C for 24 h in a ventilated room to obtain chilled carcasses. The head, thoracic cage organs, liver and kidneys were removed from each carcass to obtain the reference carcass, which included the meat, bones and fat depots.

Reference carcasses were divided into technological joints as indicated by Blasco and Ouhayoun (1996). Retail cuts were weighed and consisted of fore legs, thoracic cage, loin and hind part. The right hind legs were deboned, and the meat-to-bone ratio was calculated.

The following carcass characteristics were measured or calculated according to Blasco and Ouhayoun (1996): live weight at 87 d of age (LW87d), hot carcass weight (HCW), chilled carcass weight (CCW), reference carcass weight (RCW), total carcass length (L), lumbar circumference length (LCL), total carcass length/lumbar circumference length ratio (L/LCL), meat-to-bone ratio of the hind leg (M/B), dressing out percentage (DoP), blood ejected percentage (BeP), commercial skin percentage (CSkP), full gastrointestinal tract percentage (FGTP), drip loss percentage (DLP), head percentage (HP), set of thoracic viscera percentage (LHP), liver percentage (LvP), kidney percentage (KiP), heart percentage (HeP), lung percentage (LuP), dissectible fat percentage (DFP), fore legs percentage (FLP), thoracic cage percentage (TP), loin percentage (LP) and hind part percentage (HPP).

2.4. Determination of meat quality

Meat quality was studied with the harmonized methods proposed by the World Rabbit Science Association (Ouhayoun & Dalle Zotte 1996). The pH was measured 24 h post-mortem in *Longissimus dorsi* (pH_{24h} *Ld*) and *Biceps femoris* (pH_{24h} *Bf*) muscles, by using a pH meter with a penetration electrode (HI 98103®, Hanna Instruments, Sarmeola di Rubano, Padova, Italy). Water-holding capacity was studied in a sample of meat of the right hind leg by the pressure method on filter paper of Grau and Hamm (1957). A sample of 5 g of meat was ground in a mincer, weighed and placed between two previously desiccated and weighed 7 cm disks of Whatman No. 1 filter papers. Then the sample was placed between two plexiglass plates and a load of 2.25 kg was applied for 5 min. Finally, the meat was weighed after removing the filter papers. Water-holding capacity was calculated as the percentage of released water, PRW: [(intact meat weight − pressed meat weight) / intact meat weight] × 100. The mean of two replicates was used in pH and PRW analyses.

The moisture, CP and ash contents were determined in the *Biceps femoris* muscle of 18 rabbits randomly selected (6 for each diet), by following the procedures of AOAC (2005). The total lipid content was determined in 5 g of each homogenized sample by the gravimetric method of Folch et al. (1957).

2.5. Statistical analysis

Data were analysed as a completely randomized design with type of diet as the main source of variation, using the GLM procedure of statistical software SAS (Statistical Analysis System, version 9.3.1). Tukey's tests were used to compare means among treatments.

3. Results

3.1. Carcass characteristics

The effects of the inclusion of *A. dubius* in diets on carcass characteristics are shown in Table 2. Live weight at 87 d, HCW, RCW, LCL, M/B and percentage of ejected blood, commercial skin, full gastrointestinal tract, head, set of thoracic organs, liver, kidneys, heart, lung, fore legs and loin did not differ among the treatments ($P > .05$; Table 2).

The CCW and DoP values were higher for A0 than for A16 diet ($P < .05$). Total carcass length was higher in A32 ($P < .01$) with respect to A0 and A16 treatments. On the other hand, L/LCL value was higher for A32 than for A0 diets ($P < .05$). The values of DFP, TP and DLP were similar for A32 and A16 diets ($P > .05$) and higher than those corresponding to A0 treatment ($P < .05$). In A0 diet were observed higher values for HPP ($P < .05$) with respect to A16 and A32 treatments.

Table 2. Effect of experimental diets on carcass characteristics of rabbits at 87 d of age.

	Experimental diets[1]				
	A0	A16	A32	SEM[2]	*P*-value
Weights and measures					
LW87d (g)	1922.61	1855.97	1871.14	17.79	.125
HCW (g)	1141.72	1081.41	1108.95	14.47	.090
CCW (g)	1113.62[a]	1040.77[b]	1068.74[ab]	14.28	.028
RCW (g)	921.82	875.18	902.11	12.92	.155
L (mm)	368.00[b]	368.37[b]	379.49[a]	1.85	.007
LCL (mm)	155.39	152.46	153.17	1.09	.374
L/LCL	2.38[b]	2.42[ab]	2.48[a]	0.01	.009
M/B	7.23	6.71	6.99	0.11	.157
Proportion in LW87d, %					
DoP	57.83[a]	55.84[b]	56.92[ab]	0.32	.013
BeP	2.83	2.73	2.82	0.04	.504
CSkP	12.34	11.99	12.20	0.11	.389
FGTP	20.65	22.25	20.86	0.31	.353
Proportion in HCW, %					
DLP	2.47[b]	3.83[a]	3.61[a]	0.14	<.001
Proportion in CCW, %					
HP	10.18	10.15	10.04	0.09	.803
LHP	2.05	2.13	2.21	0.04	.169
LvP	4.27	4.47	4.21	0.07	.191
KiP	1.19	0.99	1.05	0.08	.544
HeP	0.42	0.42	0.42	0.01	.773
LuP	0.69	0.69	0.66	0.01	.585
Proportion in RCW, %					
DFP	3.02[b]	3.63[a]	3.77[a]	0.08	<.001
FLP	15.25	15.51	15.61	0.12	.455
TP	12.97[b]	13.68[a]	13.68[a]	0.12	.018
LP	28.73	28.29	28.22	0.20	.501
HPP	40.00[a]	38.95[b]	38.89[b]	0.19	.023

Notes: LW87d: Live weight at 87d; HCW: Hot carcass weight; CCW: Chilled carcass weight; RCW: Reference carcass weight; L: Total carcass length; LCL: Lumbar circumference length; L/LCL: Total carcass length/lumbar circumference length ratio; M/B: meat/bone ratio; DoP: Dressing out percentage; BeP: Blood ejected percentage; CSkP: Commercial skin percentage; FGTP: Full gastrointestinal tract percentage; DLP: Drip loss percentage; HP: Head percentage; LHP: Set of organs consisting of thymus, trachea, oesophagus, lung and heart percentage; LvP: Liver percentage; KiP: Kidneys percentage; HeP: Heart percentage; LuP: Lung percentage; DFP: Dissectible fat percentage; FLP: Fore legs percentage; TP: Thoracic cage percentage; LP: Loin percentage; HPP: Hind part percentage.
[1]A0, A16 and A32 diets include 0%, 16% and 32% of *A. dubius*.
[2]SEM: standard error of the mean (35–36 rabbits per treatment).
[ab]Values in the same row with different superscripts are significantly different ($P < .05$).

3.2. Meat quality

The effects of experimental diets on the meat quality of rabbits are shown in Table 3. No differences were observed among the treatments in the values of pH_{24h} *Ld*; pH_{24h} *Bf* and PRW ($P > .05$).

Moisture was higher in A0, followed by A16 and A32 diets ($P < .001$), while CP was higher in A16 and A32 with respect to A0 treatment ($P < .01$). Moreover, fat was higher in A32 ($P < .01$) with respect to A0 and A16 diets. Ash was higher for A16 ($P < .01$) than for A0 and A32 treatments.

Table 3. Effect of experimental diets on meat quality of rabbits slaughtered at 87 d of age.

	Experimental diets[1]				
	A0	A16	A32	SEM[2]	*P*-value
pH_{24h} *Ld*	5.43	5.47	5.49	0.03	.053
pH_{24h} *Bf*	5.72	5.80	5.81	0.01	.050
PRW (%)	16.95	17.89	17.91	0.16	.507
Proximate composition (%)					
Moisture	74.23[a]	70.99[b]	67.70[c]	0.74	<.001
CP	21.52[b]	23.76[a]	24.27[a]	0.41	.002
Fat	3.33[b]	4.16[b]	5.39[a]	0.26	.002
Ash	0.89[b]	1.10[a]	0.97[b]	0.03	.004

Notes: pH_{24h} *Ld*: pH at 24 h post-mortem (*Longissimus dorsi*); pH_{24h} *Bf*: pH at 24 h post-mortem (*Biceps femoris*); PRW: percentage of released water; CP: crude protein.
[1]A0, A16 and A32 diets include 0%, 16% and 32% of *A. dubius*.
[2]SEM: standard error of the mean (*n*: 35–36 rabbits per treatment for pH_{24h} *Ld*, pH_{24h} *Bf* and PRW; and *n*: 6 rabbits per treatment for proximate composition).
[ab]Values in the same row with different superscripts are significantly different ($P < .05$).

4. Discussion

There is no published research related to the carcass characteristics of fattening rabbits fed *A. dubius*, something which makes the present study innovative. In our trial, LW87d values were independent of the diet (Molina et al. 2015) and lower than those commonly reported for New Zealand White rabbits slaughtered at similar ages (Lebas et al. 1997). As discussed in Molina et al. (2015), the low weights observed could be the consequence of the genetic potential of the line used and the environmental conditions during the trial, because of the fact that the temperatures over the thermoneutrality range of the species reduced feed intake and, subsequently, growth rate.

Dalle Zotte (2002) reported a direct relationship between body weight at slaughter and carcass weights. These reports are consistent with the results of the present investigation, where the carcass weights (HCW, CCW and RCW) were low, and proportional to the LW87d values. Carcass weight values were lower than that reported in synthetic rabbit lines used in meat production in Western Europe that were fed commercial feeds (Hernández & Gondret 2006), while the values were similar or higher than those reported in rabbits fed feeds that include unconventional raw materials (Njidda & Isidahomen 2011). This suggests that the inclusion of *A. dubius* in diets for growing rabbits could produce carcasses of at least similar size than when diets with other unconventional ingredients are used.

According to M/B ratio in the hind leg, as a good predictor of the meat content of the whole carcass (Larzul & Gondret 2005), it was demonstrated a good meat yield, independently of the amaranth inclusion rate in the diet. With respect to the L/LCL value, the inclusion of amaranth in the diet increased the slenderness of the carcass because of its higher total length, consequently leading to poorer carcass conformation. In fact, compactness of the carcass in this study was lower than that in other studies (Pla 2008). This is an atypical result because in rabbits fed balanced diets, this parameter is generally affected only by the genotype, rearing system and management (Pla et al. 1996; Pla 2008).

Mean values of DoP (around 55%) were similar to those reported by Daszkiewicz et al. (2012) in New Zealand White rabbits slaughtered at three months of age. By contrast, Dal Bosco et al. (2012) found higher DoP (64.8%) in rabbits of similar age to those of our study. The fact that DoP values in A0 and A16 diets showed no differences with respect to A32 treatment indicates that the differences found between the treatments were independent of the presence or level of inclusion of amaranth. In fact, in studies on carcass characteristics of fattening rabbits, DoP values may vary widely, even in rabbits slaughtered at the same age, influenced by genetic factors, feeding regime, housing conditions and the specific method used for calculation (Daszkiewicz et al. 2012).

DLP indicates the loss of moisture during the chilling period and is a parameter important in determining carcass quality (Ortiz-Hernández & Rubio-Lozano 2001). In our study, the inclusion of amaranth in the diet increased DLP, which means that the meat showed a lower moisture content, thus affecting adversely its sensory properties, especially texture, and producing more lean meats (Dalle Zotte 2002). The higher fat content in diets that included amaranth (Table 1) resulted in an increased fat content in meat (Table 3), which could be related to a higher tendency for water loss and increased DLP during carcass refrigeration (Fernández & Fraga 1996; Pla & Cervera 1997).

The percentages of organs (LHP, LvP, KiP, HeP and LuP) in this trial were not affected by the treatments, in agreement with that observed in several trials of experimental diets for fattening rabbits (Rotolo et al. 2013).

The values of DFP found in this research were higher than that in most of the studies on fattening rabbits of different breeds and lines (Pascual & Pla 2007; Capra et al. 2013). The higher values of DFP in A16 and A32 (Table 2) could be related to the higher lipids content in diets (Table 1), due to the inclusion of *A. dubius* and soybean oil. High values of DFP may also be, in part, related to the relatively late slaughter age of the animals, because adipose tissue, with positive allometry, displays a late growth pattern, so rabbits with a higher degree of maturity have a higher fat percentage (Pascual & Pla 2007).

The inclusion of amaranth in the diet increased the TP, a piece that is the least valuable part of the rabbit carcass due to its high bone content (Pla et al. 1996). On the other hand, HPP decreased with the inclusion of amaranth in the diet, something that would affect the commercial value of carcass, because the hind part and the loin are the most valuable cuts in the rabbit carcass (Hernández et al. 1996). This is inconsistent with other studies, showing that HPP is not affected by feeding with diets that include unconventional vegetables (Trocino et al. 2013). The effect of diet observed in HPP and TP could be related to the fact that the low growth rate in rabbits, as shown by the animals in this study (Molina et al. 2015), affects body composition (Ouhayoun 1998) and, therefore, the proportion of each cut obtained from the technological division of the carcass. It is relevant, however, that although in our trial the slaughter weight was low (mean 1,883 g), the values of LP and HPP showed excellent performance with respect to the carcass, these being even higher than those reported by Pascual and Pla (2007) and Paci et al. (2013) for growing rabbits with average slaughter weights of 2000 and 2500 g, respectively. In the same vein, HPP values were similar to that reported by Maj et al. (2009) in New Zealand White rabbits of similar age to the animals in the present trial and slaughter weight higher than 2200 g. These are relevant results, because the loin and hind part are the most valuable cuts in the rabbit carcass (Hernández et al. 2004).

PRW observed in this study was much lower than that reported for different breeds of meat rabbits by other authors (Hernández et al. 2004; Pascual & Pla 2007) using the same press method. This indicates that the meat had a high water-holding capacity, although without depending on the inclusion level of amaranth.

The pH of rabbit meat can be affected by many factors, such as genetic type, feeding, housing conditions during fattening, carcass cooling rate and pre-slaughter handling (Hulot & Ouhayoun 1999). The pH_{24h} *Ld* and pH_{24h} *Bf* values found in the present study were lower than those reported by several authors in meat breeds (Daszkiewicz et al. 2012; Capra et al. 2013). Moreover, the *Biceps femoris* muscle presented pH_{24h} values higher than that of the *Longissimus dorsi* muscle, which was consistent with that reported by Barròn et al. (2004), who found differences in the metabolic potential of both tissues according to their function and fibre type composition. The first one has a low glycolytic potential, and therefore a higher pH (Hulot & Ouhayoun 1999). Dalle Zotte and Ouhayoun (1995) found that pH decreased with age in rabbits ranging from 56 to 84 d old. This fact could explain the low pH values observed in the present study compared to those of other authors. However, these values are yet within the range considered normal in rabbit meat (reviewed in Hulot & Ouhayoun 1999). Moreover, the inclusion of *A. dubius* in the feed, at least up to 32% DM, did not alter the pH of rabbit meat.

The inclusion of amaranth in diets affected the proximate composition of *Biceps femoris* meat. Thus, higher moisture values corresponded to the A0 treatment, while CP was higher in A16 and A32 diets including *A. dubius*. Higher ash content corresponded to the A16 treatment, while higher fat content was observed in the A32 diet. Differences observed in the proximate composition of meat could be mainly related to the proportion of fat in the diets. Thereon, Fernández and Fraga (1996) reported that adding fat to the diet lead to its accumulation in meat and carcass. This was corroborated by Pla and Cervera (1997) who found that rabbits fed diets with higher fat content showed higher proportion of fat in the hind leg, with a consequent decrease in the proportion of moisture and protein in meat. In our study, A16 and A32 diets contained more fat, which increased DFP in the carcass and EE content in meat, while moisture decreased. However, the proportion of protein in the meat increased, which can be considered an atypical result.

The moisture and CP contents of the meat in the three treatments were similar to the values reported in diverse rabbit breeds (Daszkiewicz et al. 2012; Paci et al. 2013). Conversely, ash content was lower in these same studies than in our trial. On the other hand, the fat content was higher than that reported by Paci et al. (2013); by contrast, it was lower than that reported by Peiretti et al. (2011). Moreover, Al-Dobaib et al. (2010) showed that the replacement of conventional raw materials (alfalfa hay, barley and wheat bran) in the diets by unconventional ones (corn grain, soybean, molasses and limestone) affects the content of moisture, CP and EE in rabbit meat. However, the proximate composition of the meat obtained in this study can be considered excellent and was improved by the inclusion of *A. dubius* in the diets.

It may be also noted that this trial was carried out at ambient conditions within the range that can be considered to produce thermal stress to rabbits (NRC 1996), which could affect carcass characteristics and meat quality for their effects on the biochemical profile of rabbits (Cervera & Fernández-Carmona 2010; Zeferino et al. 2013).

5. Conclusion

A. dubius can replace conventional ingredients in diets for rabbits at levels up to 32% without impacting negatively the major quality carcass characteristics or the meat quality. The results indicated that *A. dubius* can become a potential substitute for conventional raw materials in feed formulation, especially in tropical and subtropical regions.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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