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Influence of production system and feeds on performance, carcass traits and estimated energy balance of autochthonous Gochu Asturcelta pigs

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Abstract

Aim of study: To assess the effects of rearing system (extensive, ES; semi-extensive, SES) and feeds (grazed woodland, acorns, chestnuts, compound feed) on the performance, carcass traits and energetic balance of autochthonous Gochu Asturcelta pigs.

Area of study: Asturias (Spain).

Material and methods: In two successive years, a total of 58 immunocastrated Gochu Asturcelta pigs (25 females, 33 males), with an initial weight of 93.39 ± 3.36 kg and mean age of 6.82 ± 0.24 months, were randomly divided between ES and SES plots from July to December. ES pigs grazed woodland, acorns (*Quercus robur* L.) and chestnuts (*Castanea sativa* Mill.) and they were given additionally 1.5 kg compound-feed/pig·day. SES animals received only 2.5 kg compound-feed/pig·day. Chemical composition and metabolizable energy (ME) of feeds, energetic balance, growth performances and pig carcass traits were analysed.

Main results: Acorns and chestnuts were both very close in their chemical composition, except for the polyphenol content and profile, and had a lower omega-6/omega-3 ratio than compound feeds. Live weight for the ES pigs was 25% lower and carcass weight 30% lower than for SES pigs ($p<0.001$). Total ME requirement (MJ/day) was lower in ES than in SES pigs.

Research highlights: The productive and carcass parameters observed are a consequence of a lower energy intake for pigs in ES than in SES, it being necessary to drastically reduce the stocking rate to increase weight gain and to improve carcass traits when Gochu Asturcelta pigs are reared in ES.

Additional key words: silvopastoralism; celtic trunk; fatty acids; polyphenolic profile.

Abbreviations used: ADF (acid detergent fibre); CE (catechin equivalents); CP (crude protein); CT (condensed tannins); DM (dry matter); EE (ether extract); ES (extensive system); Et (ellagitannin); GAE (gallic acid equivalent); Gt (gallotannin); HEM (hemicellulose); HT (hydrolysable tannins); LW (live weight); ME (metabolizable energy); MUFA (monounsaturated fatty acids); NDF (neutral detergent fibre); PUFA (polyunsaturated fatty acids); SERIDA (Servicio Regional de Investigación y Desarrollo Agroalimentario [Regional Service for Agrifood Research and Development]); SES (semi extensive system); SFA (saturated fatty acids); TP (total phenols); UFA (unsaturated fatty acids); WSC (water soluble carbohydrates).

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Introduction

An extensive system of raising swine, based on agroforestry techniques using native rustic pig breeds, has existed in Spain for millennia, although since the first half of the 20th century it has been mainly restricted to the Mediterranean forest areas -*dehesas*- due to the massive introduction of more commercial breeds. The change in the socio-economic structure of rural areas led to the virtual disappearance of various autochthonous breeds of swine in many European countries (Egerszegi *et al.*, 2003; Crovetti *et al.*, 2007; D'Alessandro *et al.*, 2007; Royo *et al.*, 2007). However, there has been considerable interest in programs to recover autochthonous pig breeds over the last 25 years, which have proved successful in most cases. In Asturias (North of Spain), one such recovery program involves the Asturian pig, renamed as the Gochu Asturcelta pig (Argamentería & Menéndez-Fernández, 2012), an endangered local breed belonging to the Celtic trunk. These pigs have been traditionally reared in an extensive system (ES) in Iberoatlantic deciduous forests, which currently cover significant areas across Europe and are, in general, being abandoned. At present, only a very small number of traditional farmers maintain production and they sell the meat on their own farms. However, concerns over the preservation of genetic resources and the increasing number of consumers demanding such traditional local meat products, indicate that new ways of maintaining this local breed are required (Maiorano, 2009).

The conservation and the productive value of the Gochu Asturcelta are linked to the revaluation of the region's grazing woodlands, important both in terms of the sizable area they cover and their ecological value (Álvarez *et al.*, 2004), by the use of silvopastoral management. Unfortunately, little information is available on the productive performance of the Gochu Asturcelta breed in semi-extensive systems (SES) (de la Roza-Delgado *et al.*, 2012), and the feeding value of the natural resources of oak silvopastoral systems refers to those of the Mediterranean areas (Castro *et al.*, 2021).

Thus, this study aims to compare the production and carcass traits of the Gochu Asturcelta raised in an ES and fed mainly natural resources with those from a SES fed only compound feeds, and to determine the nutritional composition and estimate the metabolizable energy provided by grazed woodland, acorns (*Quercus robur* L.) and chestnuts (*Castanea sativa* Mill.) *versus* compound feeds. Additionally, the energetic balance of pigs in each production system is also estimated.

Material and methods

Authorization was obtained from the ethics committee of the University of Oviedo. Members of the research team are in possession of the accreditation of functions c (performance of procedures) and d (design of projects and procedures) according to RD 53/2013 (BOE, 2013) and ECC/566/2015 (BOE, 2015).

Experimental design

A total of 58 animals (25 females, 33 males) born in the Pig Multiplication Nucleus of SERIDA (Villaviciosa, Asturias, Spain), and with father and mother included in the Gochu Asturcelta herdbook were utilized in two successive years. At the start of the experiment (first week of July 2012) the pigs were randomly separated into two groups, to be reared under two different production systems (ES, SES) and animals of the same breed but of different origin were added to the herds in order to equalize stocking conditions in SES and ES pigs. These additional animals were not tested. Before being distributed, all the pigs were immunocastrated with a commercial vaccine (Vacsincel®- Zoetis). Mean body weight at the start of the experiment (± SEM) was 89.3 ± 3.91 kg for tested females and 96.7 ± 4.68 for tested males, with a mean age of 6.82 ± 0.29 months. All the pigs were slaughtered in December.

ES pigs were housed in three enclosed plots (P1, P2 and P3) each with eight pigs in an average area of 0.617 ± 0.037 ha/plot (rectangular plots, measuring 186.5 m in length × 33.8 m in width, along the direction of the gradient, with a slope generally over 40%) within a chestnut coppice in Sela da Loura (Asturias, 43° 23' 16.5" N, 06° 59' 50.0" W, 371 m asl). Managed stocking rate over the two studied years was 13 pigs/ha. Forty out of 48 animals were tested: 6 females and 10 males, and 10 females and 14 males in 2012 and 2013, respectively. ES pigs were fed 1.5 kg/pig·day, to complement their foraging with grazed woodland, which included wild acorns and chestnuts in the autumn, at an estimated amount of 0.5 kg nuts/pig·day for 45 days (based on estimated nut production). According to our estimate, more than 90% of the nuts were chestnuts. In addition, three weeks before slaughter, ES pigs were provided with 2.5 kg/pig·day of supplementary chestnuts not suitable for commercial sale for human consumption.

From the phytosociological point of view, the coppice is an oligotrophic oak forest with birches and chestnuts (Díaz-González, 2015) and the vascular flora shows high diversity, with the most common families being *Poaceae*, *Asteraceae* and *Rosaceae*. Approximately 50% of ground area is unforested and covered in mosses or stones (Ciordia *et al.*, 2013).

SES pigs were reared at SERIDA facilities (Villaviciosa, Asturias, 43° 28' 50" N, 5° 26' 27" W, 10 m asl) and distributed between three fenced plots (P4, P5 and P6). Each plot had an area of 100 m^2, a square 10 × 10 m design and a 10% slope and included a feed hopper, a self-filling water trough and a refuge. SES pigs received a growing diet (July-August: 3 kg/pig·day, September-October: 2 kg/pig·day), and a finishing diet (November: 2 kg/pig·day, December: 2.5 kg/pig·day) to ensure optimal slaughter weight (Argamentería, 2012). Eighteen animals were tested: 7 females and 6 males, and 3 females and 2 males in 2012 and 2013, respectively; 6 untested animals were added in 2013.

Sampling

In each of the years 2012 and 2013, a 5 kg sample collected from the grazed woodland of the ES plots was taken by walking randomly over each plot separately at the time of entry of the pigs (beginning of the summer). Individual plants were cut at soil level using a battery trimmer and the quantity of each species was in proportion to its cover (abundance-dominance rate), avoiding the collection of taxa that were rejected by the pigs. Approximately 3 kg of samples of roots were taken using a hoe up to 10 cm deep. In addition, three to five samples of each nut were collected each week over the course of a month on the land bordering the pig trial plots (0.5-1 kg), each sample consisting of at least 25 fruits. All samples were stored at 4 ºC until analysis.

Fruits were peeled manually in order to carry out compositional analysis of the kernel (including endodermis) and of the whole fruits.

Furthermore, two to four samples of the growing and finishing feeds and of the supplementary chestnuts were analysed in each year.

Compositional analysis of feeds

The dry matter (DM) content was ascertained by drying aliquots of the aerial vegetation, roots and forest fruits in a dry-forced oven (60 ºC, 24 h), which were then milled through a 0.75 mm sieve. DM content of the feed formulas was established by heating to 103 ºC for 3 h. The following chemical analyses were then performed in the Nutrition Laboratory of SERIDA, a laboratory accredited to ISO (2017): crude protein (CP = N × 6.25) by Kjeldahl analysis; ether extract (EE) by the Soxhlet technique, including sample acid digestion prior to the extraction; crude fibre (CF) by the Fibertec method (AOAC, 1995); acid and neutral detergent fibre (ADF and NDF, respectively) according to Van Soest *et al.* (1991); hemicellulose (HEM) as the difference between NDF and ADF. Starch content was determined by an enzymatic procedure after gelatinization and hydrolysis to glucose (Salomonsson *et al.*, 1984) using a YSI 2700 SELECT Biochemistry Analyzer with some modifications (Soldado *et al.*, 2003); water soluble carbohydrates (WSC) according to Hoffman (1937); fatty acid (FA) content according to Sukhija & Palmquist (1988), using the modifications of Palmquist & Jenkins (2003). Quantification of minerals followed European Commission regulation No 152/2009 methods (EC, 2009); calcium, copper, and zinc were determined after appropriate dilutions by atomic absorption spectrometry (3030 Perkin-Elmer system). Phosphorus was determined after mineralization of sample by optical density measured by a spectrophotometer UV-Vis at 430 nm (Lambda-25 Perkin-Elmer system). Total phenols (TP), condensed tannins (CT) and hydrolysable tannins (HT) expressed as gallotannins (Gts) and ellagitannins (Ets), were extracted and quantified according to Fuente-Maqueda *et al.* (2020). The metabolizable energy (ME, for growing pigs) of vegetation, fruits and compound feeds was estimated according to Noblet & Pérez (1993).

Table 1. Dry matter content (g/kg), nutritional composition (g/kg DM) and estimated metabolizable energy provision (MJ/kg DM) of grazed woodland and roots from chestnut coppice plots grazed by native Gochu Asturcelta pigs over summer months.

Variable[1]	Grazed woodland	Roots	SEM[2]	*p*-value[3]		
				Grazed woodland *vs* roots	Plot	Year
DM	267	428	32.80	0.108	0.887	0.296
Ash	101	319	8.98	**	0.623	0.663
CP	136	69.1	9.33	*	0.874	0.373
EE	20.1	4.6	0.90	**	0.190	0.184
NDF	552	718	6.37	***	**	*
NDF†	534	469	17.30	0.181	0.132	0.315
ADF	368	672	6.54	***	0.070	0.482
ADF†	346	425	13.50	0.072	0.326	0.913
HEM	188	43.7	5.53	***	**	*
ME	7.0	5.2	0.18	*	*	*

[1] DM: dry matter; CP: crude protein; EE: ether extract; NDF: neutral detergent fibre (NDF†: ash free); ADF: acid detergent fibre (ADF†: ash free); HEM: hemicellulose; ME: metabolizable energy (Noblet & Pérez, 1993). [2] SEM: standard error of the mean. [3] *p*-value: statistically significant effect of vegetation, plot or year: *** $p<0.001$; ** $p<0.01$; * $p<0.05$.

Final live weight and carcass traits

Pigs, with an average age of 12.3 months, were transported in an open, wooden-bodied truck to a commercial slaughterhouse located 50-150 km from the experimental sites. Final live weight (LW) was determined for animals. Carcasses were weighed and measurements of carcass length, ham length and ham perimeter were assessed using a metric tape measure (Hansson & Lundstrom, 1989). Backfat thickness was measured with a gauge at the last rib level and along the mid-dorsal line at the level of the midpoint of the *Gluteus medius* muscle (Temperan *et al*., 2014). The pH and temperature were measured in triplicate at 24 h *post-mortem* with a puncture electrode and penetration probe at the *Gluteus medius* muscle level.

Estimation of energy balance

The ME requirements of each animal were estimated as a function of the initial and final live weight, the monthly average temperature and the dimensions and slope of the enclosures and plots (Rodríguez-Estévez *et al.*, 2010). The meteorological data used was that recorded at the SERIDA farm weather station for the SES production system and that from the National Agency of Meteorology for the ES production system. Based on these data, the daily mean temperature over the two years from July 1 to December 31 was 16 ºC and 14 ºC for SE and SES, respectively. For the SES, total ME intake was estimated as that supplied by the compound feeds provided to animals. In the case of ES, ME supplied by the biomass of grazed woodland and forest fruits ingested was estimated as: [Total ME (estimated) requirement] – [ME (estimated) provided by 1.5 kg of rearing feed].

As far as pig behaviour is concerned, a fortnightly visit to the plots was made to collect data and to observe the behaviour of all the pigs in the ES regime. These visits lasted a minimum of 6 hours and sometimes up to 10 hours. The pigs chose a place as flat as possible to sleep, which implied proximity to the centroid of the plot. They walked very slowly, on the lines with the least slope and in groups, making the most of the daylight hours. From the changes in position, we estimated a route ten times the length of the plot and five times the width, to explore the entire surface. A total daily distance of $10 \times 186.5 = 1865$ m in the horizontal direction and $5 \times 19.2 = 96$ m in the vertical direction was estimated.

The theoretical energy requirements of pigs (metabolizable energy, MJ/pig·day) in the two production systems were estimated for Maintenance = $0.396 * LW^{0.75}$ according to Barea *et al.* (2007a,b) obtained in Iberian pig trials; thermoregulation = $21.3 * LW^{0.75} * (23\text{-t ºC})/1000$ (ARC, 1980). Activity in the ES system was considered as the sum

Table 2. Nutritional characteristics of the feeds consumed by Gochu Asturcelta pigs (acorns, chestnuts and compound-feeds, g/kg DM).

Variable[1]	Fruits				Compound-feed		SEM[2]	*p*-value[3]			
	Acorns	Wild chestnut	Suppl. chestnut: Whole chestnut	Suppl. chestnut: Kernel	Fattening	Finishing		Fruits *vs* compound-feeds	Acorns *vs* chestnuts	Wild chestnut *vs* suppl. whole chestnut	Kernel *vs* suppl. whole chestnut
DM (g/kg)	419	392	427	438	892	891	13.50	***	0.852	0.423	0.854
Ash	24.1	21.8	21.6	22.1	58.3	52.7	0.81	***	0.278	0.834	0.218
CP	62.8	70.2	69.7	75.9	128	111	2.12	***	0.315	0.949	0.155
EE	32.3	23.8	22.0	30.8	44.2	37.2	1.85	**	0.218	0.766	***
CF	nd	nd	nd		41.3	42.6	4.08	-	-	-	
NDF	493	455	450		182	183	16.10	***	0.359		
NDF †	485	447	439	350	181	173	11.50	***	0.248	0.894	*
ADF	226	231	201		66.2	52.2	24.10	***	0.922		
ADF †	219	228	196	65	65.5	55.2	17.70	**	0.839	0.580	*
HEM	266	219	246	285	116	117	13.60	***	0.656	0.545	0.109
Starch	372	285	341	463	500	545	17.70	***	0.783	0.235	**
WSC	56.1	107	147	199	71.2	24.4	15.14	***	*	*	*
ME (MJ/kg DM)	10.3	10.7	11.1	12.9	14.4	14.6	0.22	***	0.318	0.260	*
Calcium	0.99	1.0	0.95		10.0	2.1	0.13	***	0.720	0.472	
Phosphorus	0.90	0.95	1.2		4.9	3.1	0.06	***	0.786	0.199	
Copper (mg/kg DM)	5.7	6.2	7.6		18.0	13.2	0.40	***	0.313	0.179	
Zinc (mg/kg DM)	10.0	15.9			164	122	1.57	***	*	*	

[1] DM: dry matter; CP: crude protein; EE: ether extract; CF: crude fibre; NDF: neutral detergent fibre (NDF†: ash free); ADF: acid detergent fibre (ADF†: ash free); HEM: hemicellulose; ME: metabolizable energy; WSC: water soluble carbohydrates. nd: not determined. [2] SEM: standard error of the mean. [3] *p*-value: ***$p<0.001$; ** $p<0.01$; *$p<0.05$.

of standing = 0.29 * $LW^{0.75}$ * Min /1000 (Noblet *et al.*, 1993) plus horizontal shift = 3.55 * LW * length/1000000 and vertical shift = 51.5 * LW * height / 1000000 obtained in Iberian pigs (Lachica & Aguilera, 2000), while in the SES system, ME for shift = 0.10 * ME for maintenance, assuming that the activity of pigs in parks is covered with 10% of the maintenance needs (Barea *et al.,* 2007a,b). Finally, weight gain = 41.4 * ΔW (kg/day), assuming an efficiency net energy / metabolizable energy k_w = 0.80 (Barea *et al.*, 2007a,b). (LW = live weight in kg; t ºC = environmental temperature in Celsius degrees; ΔW = live weight increase in kg/day).

Statistical analysis

The SAS (1999) statistical package was used, applying the models described below. Y = dependent variable, μ = general mean and ε = error. Statistical significance was set at $p< 0.05$.

Comparisons were made between grazed woodlands and roots composition by a GLM procedure according to the model: Y = μ + year + plot + vegetation + year * vegetation + plot * vegetation + ε; where, vegetation = grazed woodlands or roots; year = first or second; plot = one, two or three. The contrasts depend on the significance of the interactions.

A GLM procedure was also used to make comparisons between feeds used in the experiment following the model: Y = μ + year + class + feed (class) + year * class + year * feed (class) + ε; where, class = fruit or compound feed; feed = acorn, wild chestnut or supplementary chestnut nested to fruit, or, growing or finishing nested to compound feed, and year = first or second. The final means for comparisons were generated by orthogonal polynomials.

The phenolic profiles of the different fruits were analysed according to the model: Y = μ + fruit + parts fruit + year + fruit * parts fruit + fruit * year + parts fruit * year + ε; with the fixed effects fruit = acorn or chestnut, and, in addition, parts fruit = fruits with shell (whole fruit) or not (kernel) and year = 2012 or 2013. The final comparisons of significant fixed effects were estimated by the least-squares means (LS-means) procedure.

The comparison of growth performance and carcass characteristics between the ES or SES rearing regimes was analysed following a model of analysis of covariance according to the model: Y = μ + year + sex + regime + year * sex + year * regime + sex * regime + year * sex * regime + weight at 6 months + ε; where year, sex and regime were fixed effects. When the covariable weight at 6 months was not significant it was removed from the model. To ensure linear independence between observations, each plot was considered as an experimental unit by averaging overall data.

Table 3. Fatty acid profiles of the feeds used in the experiment (acorns, chestnuts and compound feeds, g fatty acid methyl ester/100 g total fatty acid identified).

Variable	Fruits				Compound feed		SEM [1]	*p*-value [2]			
	Acorns	Wild chestnut	Suppl. chestnut		Fattening	Finishing		Fruits *vs* compound feeds	Acorns *vs* chestnuts	Wild chestnut *vs* suppl. whole chestnut	Kernel *vs* suppl. whole chestnut
			Whole chestnut	Kernel							
Caproic (C6:0)	0.061	0.063	0.336	0.62	1.27	0.307	0.1125	*	0.808	0.404	0.495
Heptanoic (C7:0)	0.000	0.000	0.002	0	0.083	0.000	0.0040	***	0.920	0.924	0.999
Caprylic (C8:0)	0.021	0.024	0.136	0.09	0.131	0.251	0.0166	***	0.622	0.803	0.495
Nonanoic (C9:0)	0.012	0.022	0.054	0.043	0.104	0.081	0.0136	0.825	0.519	0.815	0.495
Capric (C10:0)	0.020	0.000	0.032	0.012	0.079	0.225	0.0116	**	0.617	0.902	0.495
Lauric (C12:0)	0.059	0.027	0.109	0.05	0.607	2.21	0.0944	***	0.905	0.984	0.495
Myristic (C14:0)	0.052	0.020	0.221	0.13	0.517	1.14	0.1025	**	0.590	0.810	0.495
Pentadecanoic (C15:0)	0.147	0.115	0.243	0.116	0.004	0.000	0.0211	*	0.106	0.727	0.495
Palmitic (C16:0)	26.4	30.8	32.1	33.6	30.7	38.2	2.27	0.450	0.274	0.622	0.669
Palmitoleic (C16:1)	0.354	0.219	0.072	0.16	0.000	0.000	0.0486	0.371	0.164	0.501	0.495
Heptadecanoic (C17:0)	0.030	0.000	0.022	0.043	0.000	0.000	0.0074	0.337	0.125	0.271	0.999
Stearic (C18:0)	0.89	0.74	0.96	0.46	3.12	1.59	0.1017	***	0.879	0.758	0.190
Oleic (C18:1 c)	20.4	15.3	11.2	8.2	15.1	14.8	1.42	0.182	0.182	0.298	0.120
Vaccenic (C18:1)	0.568	0.043	0.241	0.5	0.578	0.317	0.0854	0.057	0.057	0.398	0.495
Arachidic (C20:0)	0.034	0.000	0.000	0	0.000	0.000	0.0080	0.270	0.270	1.000	0.999
Linoleic (C18:2)	44.7	47.2	48.4	51.5	44.7	39.2	2.90	0.589	0.247	0.900	0.330
Linolenic (C18:3)	6.15	5.37	5.94	4.4	3.19	1.77	0.712	0.893	0.662	0.713	0.318

[1] SEM: standard error of the mean. [2] *p*-value: *** p<0.001; ** p<0.01; * p<0.05.

Table 4. Total fatty acids: saturated, monounsaturated, polyunsaturated, unsaturated and 9, 7, 6 and 3 omega series fatty acids (g/100 g total identified) of fruits and compound-feed.

Variable [1]	Fruits			Compound-feed		SEM [2]	*p*-value [3]		
	Acorns	Whole chestnut		Fattening	Finishing		Fruits *vs* compound-feeds	Acorns *vs* chestnuts	Wild chestnut *vs* suppl.
		Wild chestnut	Suppl. chestnut						
SFA	27.8	31.9	33.4	36.4	43.9	3.26	*	0.414	0.657
MUFA	21.3	15.5	11.6	15.7	15.1	0.97	0.548	0.139	0.321
PUFA	50.8	52.6	54.7	47.9	40.9	2.97	0.080	0.400	0.804
UFA	72.2	68.1	66.3	63.6	56.1	2.82	*	0.397	0.612
n-9 MUFA	20.4	15.3	11.2	15.1	14.8	1.42	0.553	0.182	0.298
n-7 MUFA	0.92	0.26	0.37	0.58	0.32	0.15	0.780	*	0.741
n-6 PUFA	44.7	47.2	48.4	44.7	39.2	2.90	0.260	0.247	0.330
n-3 PUFA	6.15	5.37	6.30	3.19	1.77	0.73	*	0.662	0.318
n-6:n-3 ratio	9.43	12.4	9.61	16.6	24.9	2.08	*	0.537	0.686

[1] SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; UFA: unsaturated fatty acids. [2] SEM: standard error of the mean. [3] *p*-value: *** $p<0.001$; ** $p<0.01$; * $p<0.05$.

The theoretical energy requirements of pigs in the two production systems were analysed following the same model as that of growth performance and carcass characteristics, disregarding the sex factor.

Results

Chemical composition and metabolizable energy of grazed woodland, nuts and compound feeds

The Plot (P) factor had a statistically significant influence on the nutritional characteristics of aerial vegetation, for HEM and ME, with levels of HEM decreasing as follows: 242 (P3) > 186 (P2) > 136 (P1) g/kg DM ($p<0.01$). High HEM concentrations reduced the estimated ME intake significantly, following the pattern: 5.8 (P3) < 7.3 (P2) < 7.8 (P1) MJ/kg DM, ($p<0.05$). No significant differences were observed between aerial woodland and roots in terms of DM content, ($p=0.1080$) and neither for ash-free NDF and ADF. The roots showed higher ash content in both NDF and ADF, approximately 35 and 37%, respectively, compared to 3 and 6% in the vegetation. The ash content of the roots was up to ten times higher in NDF and six times higher in ADF ($p<0.01$) than in the grazed woodland. EE ($p<0.01$) and HEM ($p<0.001$) contents in available vegetation were five times greater than in roots (Table 1). Differences between years and plots were observed for HEM and ME.

With respect to fruits, significantly higher values were found for WSC and zinc in both wild and supplementary chestnuts than in acorns (Table 2), the FA profiles of nuts being very similar (Table 3).

However, there were clear differences in nutritional composition between fruits and compound feeds. Acorns and chestnuts had significantly lower values for DM, ash, CP, EE, starch, ME, calcium, phosphorus, copper and zinc than compound feeds, but they exhibited a significantly higher content of NDF, ADF, HEM, WSC (Table 2), pentadecanoic acid (Table 3) and total UFA and n-3 PUFA (Table 4). Furthermore, they showed reduced concentrations of certain FAs: caproic acid, lauric acid, myristic acid, stearic acid (Table 3), SFA and omega-6/omega-3 ratio, compared to compound feeds (Table 4).

The results of the polyphenolic characterization of the whole and kernel wild chestnuts and acorns are shown in Table 5. A higher concentration of TP was observed in acorns than in chestnuts. Important significant differences ($p<0.001$) were detected for HT between the two wild fruits: acorns contained six times more Gts ($p<0.001$) and twenty times more Ets ($p<0.001$) than chestnuts, in both whole fruits and kernel, Ets being the predominant HT present. The significant interactions observed were Fruit*Year ($p<0.001$), Year*Parts fruit ($p<0.01$) and Fruit*Parts fruit ($p<0.001$).

Growth performance and carcass characteristics

The influence of production system on growth performances and carcass characteristics of pigs is presented in Table 6. The SES resulted in significantly higher values for growth and most carcass parameters, with the exception of temperature (ºC) at 24 h *post-mortem.* Other parameters such as carcass yield and 24h pH were not different. Live weight for the ES pigs was 25% lower and carcass weight 30% lower than for SES pigs ($p<0.001$), due to differences in weight gain in the last five months of life (20 ± 0.4 *vs.* 49 ± 3.4 kg), these data indicating a very low growth rate for ES pigs. The *Year* factor was not significant. Nevertheless, there was a significant effect of *Year* in daily weight gain ($p<0.001$), this being higher in 2013, in spite of lower carcass weight for both the ES and the SES regimes ($p<0.05$).

Table 5. Polyphenolic characterization of the whole fruit and kernel of wild chestnuts and acorns (years 2012 and 2013).

Variable [1]	Chestnut				Acorn				SEM [2]
	Whole		Kernel		Whole		Kernel		
	2012	2013	2012	2013	2012	2013	2012	2013	
TP (g GAE/kg DM)	17.5	12.2	10.6	4.4	27.2	54.9	28.8	63.5	1.138
CT (g CE/kg DM)	0.38	0.62	0.13	0.12	0.26	1.12	0.17	1.29	0.101
Gts (g MG/kg DM)	0.75	0.48	0.28	0.09	1.89	2.63	2.11	3.04	0.062
Ets (g EA/kg DM)	0.60	0.38	<LQ	<LQ	4.71	5.11	5.31	5.91	0.055

	p-value [3]						
	Chestnut *vs* Acorn	Whole *vs* Kernel	2012 *vs* 2013	Interactions			
				Fruit×Year	Fruit×Part	Year×Part	Fuit×Year× Part
TP (g GAE/kg DM)	***	0.170	***	***	***	0.072	*
CT (g CE/kg DM)	***	*	***	***	*	0.951	0.098
Gts (g MG/kg DM)	***	0.193	***	***	***	0.132	0.543
Ets (g EA/kg DM)	***	*	***	***	***	*	0.886

[1] TP: total phenols (GAE: gallic acid equivalents). CT: condensed tannins (CE: (+)-catechin equivalents). Gts: gallotannins (MG: methyl gallate). Ets: ellagitannins (EA: ellagic acid). DM: dry matter. LQ: limit of quantification. [2] SEM: standard error of the mean. [3] *p*-value: *** $p<0.001$; ** $p<0.01$; * $p<0.05$.

Regarding the effect of *Sex*, females showed lower daily weight gain than males ($p<0.05$), and there was a significant effect of the interaction *Year***Production* system in terms of carcass temperature at 24 h post-mortem and ham perimeter ($p<0.05$).

Estimated energy balance and ingestion of grazed woodland, roots and forest fruits

The theoretical energy requirements of pigs in the two production systems are shown in Table 7. According to the estimations, SES pigs needed to invest significantly more energy in maintenance than ES pigs (14.36 *vs* 12.80 MJ/day, $p<0.001$). The estimated energy requirements for thermoregulation, although higher in ES pigs (6.20 *vs* 5.41 MJ/day), were not significant ($p=0.115$) and the same was true of the feeding level ($p=0.066$).

Considering standing and both horizontal and vertical shifts made by Gochu Asturcelta pigs, the estimated activity costs were significantly higher in ES than in SES (4.56 *vs.* 1.44 MJ/pig·day, respectively), ($p<0.001$). In contrast, ES pigs required less total metabolizable energy than SES pigs (28.15 *vs.* 34.83 MJ/pig·day, respectively, ($p<0.001$) due to the lower live weight of ES pigs. Weight gains were three times less in ES than in SES. Therefore, the calculated total ME requirement (MJ/day) taking into account all the mentioned parameters were lower in ES than in SES pigs.

Discussion

To our knowledge, this is the first time that the physical and chemical composition of the grazed vegetation of a chestnut coppice ecosystem in Northern Spain has been published, as is also true of the investigation of its potential influence on the extensive rearing of the autochthonous rustic pigs, Gochu Asturcelta.

Different botanical composition of the plots (data not shown) could explain differences related to ME values: P1, with the lower ME level, had a higher abundance of grasses than P2 and P3, including species such as *Holcus lanatus* L., and *Agrostis capillaris* L., which are characterized by a very narrow leaf and, therefore, have a low leaf:stem ratio. Plot P3, on the other hand, had the highest number of vascular species with broad leaves (for example *Anemone nemorosa* L., *Geranium robertianum* subsp. *purpureum* (Vill.) Nyman and *Lysimachia nemorum* L.), while P2 showed an intermediate botanical composition. In addition, the concentration of HEM was higher in 2013 than in 2012 (213 *vs.* 163 g/kg DM, $p<0.05$), in agreement with the lower estimated ME (6.1 *vs*. 7.9 MJ kg/DM, $p<0.05$), respectively. These plots are representative of the chestnut habitat, used for the combination of silvopastoral management with the rearing of native pig breeds of the Celtic trunk as a strategy compatible with the conservation of the chestnut habitat and promoting its biodiversity, contributing to the recovery and conservation of these native pig breeds.

Although it has been observed in other studies (García-Valverde *et al.*, 2007) that Iberian pigs remove the shells from wild fruits, unexpectedly, the ES pigs ingested both fruits whole, including the shell, which may have contributed to increasing the pigs' satiety. The chemical analysis of the shell of the supplementary chestnuts suggested that shell had low nutritional value, as whole fruits had higher levels than kernels only for NDF and ADF. ES pigs proceeded to remove the shells of the supplementary chestnuts

Table 6. Influence of production system on growth performances and carcass characteristics of the native Gochu Asturcelta pig reared in two production systems (mean ± SEM).

Variable	Extensive system		Semi-extensive system		*p*-value[1]			
					Production system	Year	Sex	Significant interactions
Live weight at slaughter (kg)	113	± 3.4	144	± 3.4	***	0.107	*	
Daily weight gain (g/day)	111	± 20.9	329	± 20.9	***	***	*	
Carcass weight (kg)	86	± 3.1	112	± 2.8	***	*	*	
Carcass yield (%)	75.9	± 0.50	77.2	± 0.53	0.101	**	0.856	
pH 24 h	6.11	± 0.16	6.31	± 0.16	0.113	0.527	0.185	
Temperature 24 h (ºC)	6.61	± 0.29	6.08	± 0.29	**	0.642	0.843	Year×Production system *
Carcass length (cm)	88	± 0.9	93	± 0.9	***	*	0.565	
Leg length (cm)	66	± 0.8	68	± 0.8	*	0.074	0.200	
Ham length (cm)	40	± 0.8	43	± 0.8	*	0.756	0.480	
Ham perimeter (cm)	68	± 1.4	77	± 1.4	***	0.975	0.177	Year×Production system *
Hand length (cm)	39	± 0.6	41	± 0.8	0.057	0.549	0.966	
Metacarpal circumference (cm)	22	± 0.6	26	± 0.6	***	0.392	0.377	
Back fat thickness (cm):								
Last rib level	2.41	± 0.22	3.36	± 0.22	***	0.096	0.517	
Gluteus middle-level	2.68	± 0.25	4.53	± 0.28	***	0.114	0.057	

SEM: standard error of the mean. [1] *p*-value: statistical significance of effect of plot and year. *** $p<0.001$; ** $p<0.01$; * $p< 0.05$.

when these were the main component of their daily food allowance. ES pigs probably behaved differently when fed wild chestnut fruits *vs.* the supplementary ones because when nuts were scarce the animals ingested the whole fruit to satiate.

The nutritional composition and fatty acid profile of acorns and chestnuts were compared with those available from the Feed Information Service of the University of Córdoba, Spain (SIA, 2013). In the case of chestnuts, our data were within the range of those described by the SIA. Chemical composition and estimated ME content were also in line with those published by Nieto *et al.* (2002), who determined the crude protein digestibility and energy values of chestnut fruits in Iberian pigs.

The results on the fibrous nature of the shell also concur with those obtained by Pereira-Lorenzo *et al.* (2006) for kernel chestnuts from selected cultivars from several Spanish regions (including Asturias), with the exception of starch and total phosphorus content, with lower values than those of the main Spanish chestnut cultivars, while calcium content was up to two times higher, which could be attributed to edaphic differences. Comparing these results with those for selected cultivars of chestnut on the island of Tenerife (Hernández-Suárez *et al.*, 2012), higher concentrations of WSC found in this case, while the FA profiles in this study are in agreement with data from Astorga-España *et al.* (2011), except for our higher palmitic acid and lower oleic acid concentrations.

Nevertheless, the *Q. robur* acorns consumed in this study differed in the relative proportions of their nutrient composition, when compared to the species of the main oak forests, or *dehesas*, in Spain: *Quercus ilex* L (holm oak), *Quercus suber* L. (cork oak) and *Quercus faginea* Lam. (Portuguese or Valencian oak). DM, EE and starch content were all lower in these samples (30%, 55% and 31%, respectively); a somewhat lower WSC content was also observed in the present study (25%), meaning that ME was lower (38%). In contrast, concentrations of NDF, ADF and the HEM fraction were higher (22%, 33.7% and 13%, respectively), suggesting more lignified cell walls in these acorns. Nevertheless, in Pyrenean oak acorns (*Quercus pyrenaica*) the contents of EE (1.9% DM) and NDF (44.5% DM) are close to the averages found here. As regards mineral elements, the fruits of the current study displayed lower calcium and zinc content than acorns from the *dehesas*, although phosphorus and copper contents were very similar.

With reference to saturated FAs (SFAs), palmitic acid content was consistently higher than that of the other saturated acids such as stearic acid, as was reported for *dehesa* acorns. With respect to unsaturated FAs (UFAs), the acorns in this study consistently showed a reduced content of oleic acid (65%) and increased linoleic (52%) and linolenic acid (67.5%) content. The latter two could cause fat softening problems in the final product (López-Bote *et al.,* 2001).

Table 7. Theoretical energy requirements of Gochu Asturcelta pigs in two production systems expressed as metabolizable energy (MJ/day).

Variable [1]	Production system			
	Extensive	Semi-extensive	SEM [2]	*p*-value [3]
Estimated energy requirements (MJ/day)				
Maintenance = 0.396*LW$^{0.75}$	12.80	14.36	1.221	***
Thermoregulation = 21.3*LW$^{0.75}$*(23-t ºC)/1000	6.20	5.41	0.514	ns
Standing = 0.29*LW$^{0.75}$*Min /1000	3.38			
Horizontal shift = 3.55*LW*length/1000000	0.67			
Vertical shift = 51.5*LW*height/1000000	0.51			
0.10 * Maintenance		1.44		
Physical activity	4.56	1.44	0.306	***
Weight gain = 41.4*ΔW (kg/day)	4.60	13.62	2.628	***
Total energy requirements	28.15	34.83	3.861	***
Feeding level (Total energy requirements/Maintenance)	2.20	2.43	0.176	ns
Estimated metabolizable energy provided (MJ/day)				
Fattening feed	19.81	33.02		
Woodland resources	8.34		1.045	

[1] LW=live weight (kg). t ºC=room temperature. Δ: increase. Activity in extensive: Standing + Horizontal shift + Vertical shift. Activity in semiextensive: 0.10*Maintenance. [2] SEM: standard error of the mean. [3] *p*-value: *** $p<0.001$; ** $p<0.01$; * $p<0.05$.

The lower SFA content found in the wild chestnuts, together with their better omega-6/omega-3 ratio than compound feed values, is an interesting finding, as it is well known that a lower omega-6/omega-3 ratio contributes to reducing the risk of many of the chronic human diseases highly prevalent in Western societies, as well as in developing countries (Simopoulos, 2008). Since feed composition affects the FA profile of pig meat and given that mammalian cells cannot convert omega-6 to omega-3 because they lack the converting enzyme omega-3 desaturase (Simopoulos, 2002), the inclusion of wild fruits to partially or totally replace compound feed in the finishing diet of Gochu Asturcelta pigs could potentially have interesting and important health benefits.

Lee *et al*. (2016) demonstrated that the nutritional value of the chestnut kernel was considered very suitable for pig feed due to its high "crude protein and energy content, high dry matter and protein digestibility and absence of tannin". These authors found a higher tannin content, measured by the Folin-Dennis method, in the endodermis (inner skin) than in the other tissues, but Barreira *et al*. (2008) found the following gradient of tannin concentration in various chestnut tissues, outer skins>inner skins>flowers>leaves>>>fruit, using Folin and Cicolteau's phenol reagent. Our study used this latter method, and found that the outer skin (shell) of the chestnut appears to contribute significantly to TP, and both families of HTs, given the differences between levels in kernels and whole fruits.

The kernel of the wild chestnuts in this study contained a slightly higher quantity of TP, expressed as g gallic acid equivalent (GAE)/kg DM (10.59 and 4.41, for 2012 and 2013 respectively), than the Tenerife varieties (1.96-4.31 g GAE/kg DM) reported by Hernández-Suárez *et al*. (2012), probably due to the presence of the inner skin in our samples. A kernel chestnut intake of between 0.6 and 0.4 kg DM/pig·day implies the ingestion of 6.35-1.76 g GAE/day of TP. If pigs are reared with whole chestnuts, the range of ingested polyphenols is slightly higher, 10.52-4.88 g GAE/day.

In the case of acorns, TP levels in this work were higher than those described by Tejerina *et al*. (2011), and far higher than in chestnut, although both tannin families are within the range described by these authors. However, the influence of this would have been rather limited, since acorns were only present for one month during the autumn foraging in ES.

The findings obtained in SES concerning growth performance and carcass traits were in agreement with previous studies (Argamentería & Menéndez-Fernández, 2012), despite the low sample size of pig herds, particularly in 2013. Live weight at slaughter of the Gochu Asturcelta ES pigs was found to be inferior to that reported by Peinado *et al*. (2004) in the study of Chato Murciano, an autochthonous pig breed from the region of Murcia (Spain) bred outdoors. Nevertheless, the LW is highly dependent on feeding level. Moreover, carcasses from animals raised in the ES system did not satisfy the requirements of the Asturian meat sector because they were too small as a result of insufficient ME intake, even though the rearing environment may well potentially have positive effects on pig carcass evaluation (BOE, 2018).

It is worth noting that the stocking rate described for Iberian pigs in the traditional Spanish *dehesa* system varies according to various authors: 1.84-2 pigs/ha (Buxadé, 1984), 0.7 pigs/ha (Daza, 2001) and, 1-1.5 pigs/ha (López-Bote *et al*., 2001). Acorn production in *dehesa* systems ranges from 300 to 700 kg/ha (180-420 kg DM/ha) according to Rodríguez-Estévez *et al*. (2007). In the present study, acorn and chestnut production was estimated to be rather low and proved insufficient to feed the ES pigs, indicating that the experimental stocking rate of 13 pigs/ha is excessive, although this stocking rate was selected since it is used with native pigs belonging to the Celtic trunk reared in ES in Iberoatlantic deciduous forests and because of the absence of information from previous studies on these autochthonous pigs.

To the best of our knowledge this is the first time that ME requirements have been calculated for Gochu Asturcelta bred in an ES regimen in Iberoatlantic deciduous forests. The calculation of the needs in metabolizable energy (MJ/pig·day) was carried out according to Rodríguez Estévez *et al.* (2010) as specified in the Material and Methods section. As expected, the activity costs for standing and locomotion (horizontal and vertical shifts) were higher in ES than in SES, while in agreement with Barea *et al.* (2007a,b) it was assumed that the activity of the SES pigs in the plots was covered with 10% of the maintenance needs (See Table 7). In contrast, ES pigs required less energy for maintenance since the weights of the animals were lower than in SES regime.

The growth rates obtained are quite low, particularly in ES pigs. This indicates that the pigs were malnourished. The resources provided did not allow the animals to express their growth potential. All this suggests that the stocking rate was not chosen properly, but we must not forget that this is the first study carried out on this native breed, which is at risk of disappearing.

The protein contribution of the resources available in chestnut coppice could be a limiting factor, at least in the case of ES pigs. Firstly, with respect to the aerial vegetation, our study indicates that the CP content of grazed pasture (136 g/kg DM) is consistent with that reported by the Feed Information Service of the University of Córdoba, Spain (SIA, 2013), but lower than the green forage with a high proportion of legumes that has been shown to be a good source of protein for pigs (Edwards, 2003; Garcia-Valverde *et al*., 2007). Moreover, the high content of NDF and ADF of the aerial vegetation of the coppice casts doubt on its effects on total nutrient ileal digestibility. Furthermore, regarding the production of fruits from chestnut coppices, it has been estimated at 270 kg/ha of chestnuts and 30 kg/ha of acorns (unpublished data). Based on the ME values obtained for these nuts (Table 2), they would contribute 2.16 MJ/pig·day, to which the low energy contribution of aerial vegetation and roots should be added. The ME provided by forest resources does not reach the 8.34 MJ/day estimated as the difference between the total requirement of ME (estimated) and the ME (estimated) provided by 1.5 kg of feed for breeding. However, it is necessary to emphasize that the quantifications are based on estimates. In spite of this, it can be stated that the energy contribution of chestnut coppice resources is very low.

These low production data of the chestnut coppice contrast with those of grafted orchards for which Bellat & Dasque (2019) have indicated an average of 1,360 kg/ha in EU plantations, but it must be considered that the chestnut production in a coppice tends to be lower as it is managed for timber production. In addition, in these ecosystems oaks are scarce, to which must be added an acorn production that varies greatly between individual trees, years, and locations, which directly affects oak regeneration as well as the population of wildlife species that depend on acorns for food (Rose *et al*., 2011). This low productivity of the chestnut coppice is evinced as the main problem to be solved in the extensive production of Gochu Asturcelta in the arboreal pastures in Iberoatlantic deciduous forests.

Based on all the above considerations, the decision was made to maintain 1.5 kg kg/pig·day of compound feed during the experiment in ES pigs, as well as to provide additional chestnuts in ES. However, and considering the rather low pig growth rates obtained in ES, this amount proved to be insufficient.

According to the calculations shown in Table 7, the level of feeding in the ES only reached a value of 2.2 × maintenance energy requirements, compared to 2.43 × maintenance energy requirements in the SES pigs. The perennial plants in the forest plots have only a limited capacity for regrowth, meaning that as the animals consumed them, the nutritional capacity of the plots decreased progressively throughout the summer period.

Concerning the SES regime, the concordance between the estimations of ME requirements and ME provided by the intake of compound feed is rather close. In ES, according to the data in Tables 1 and 2, to reach 8.34 MJ/pig·day (Table 7), on the basis of summer grazed woodland and roots, acorns and chestnuts, the respective intakes should be either 1.2, 1.6, 0.82 or 0.76 kg DM/pig·day. In summer, while pigs spend most of their active time rooting, it was regularly observed that the weight of each piece of root ingested was far lower than individual bites of grazed woodland. Therefore, for the summer period we could assume (by direct observation) that, to reach 8.34 kg MJ/pig·day, an intake of 0.7 kg DM/pig·day of vegetation plus 0.7 from roots would be required. In autumn, the contribution of grazed woodland intake can be considered as negligible, but pigs continue rooting for food. A combination of 0.45 kg DM/pig·day of wild fruits plus 0.7 of roots could be assumed for distribution of intake for this period.

Low intensity grazing systems can succeed by valorising a natural conservation strategy to maintain pasture landscapes in combination with the profitable and healthy production of meat and other livestock products (Hussain & Jaweed, 2017); furthermore, there are now more consumers that perceive this traditional rearing system as being more environmentally friendly, with improved animal health, and who are aware of the importance of the conservation of the native pig gene pool. In this context, our findings suggest the recommendation of the use of Iberoatlantic deciduous chestnut woodlands in the feeding of Gochu Asturcelta pigs, although carcass results fail to satisfy the requirements demanded by the meat sector. Nevertheless, there is still room to significantly improve animal production in ES by means of three individual strategies or combinations of them: reducing stocking rate of Gochu Asturcelta pigs, supplying additional feed, or increasing the production of the chestnut coppice's own resources through efficient management approaches based on selected thinning. A reduction of the stocking rate to 1.5 pigs/ha would allow the equalization of swine production in the ES and SES systems but it would be economically unacceptable for the interests of pig breeders as a management system. On the other hand, with regard to the supply of additional feed, the increased supplementation does not necessarily have to be restricted to the use of compound feed, as the availability of high-protein forages would increase both energy and protein intake. An adequate chestnut management program could increase both fruit and forage production with these characteristics.

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