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Feed conversion rate and estimated energy balance of free grazing Iberian pigs

Vicente Rodríguez-Estévez *, Manuel Sánchez-Rodríguez, Antón García, A. Gustavo Gómez-Castro

Departamento de Producción Animal, Facultad de Veterinaria, Universidad de Córdoba, Campus de Rabanales, Córdoba 14071, Spain

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ABSTRACT

A direct *in situ* observation method has been used, observing ingestive bites taken by continuously monitored Iberian pigs (10 uninterrupted hours, from 08:30 to 18:30) to calculate intake of acorns and grass and grazing activity during the fattening period in the *dehesa* (cleared Mediterranean forest like savannah) from November first to the end of December. The obtained results, together with measurements of weight gain, have been used to propose a new method for calculating stocking rate capacity. 60 grazing days have been studied corresponding to different randomly chosen Iberian pigs (110.2 ± 1.3 kg of average initial LW) during 2 months. The results show a daily intake of 56.4 ± 2.34 MJ ME from grass and acorns, of which acorns accounted for 90.42% (2.92 ± 0.13 kg of kernel DM and 0.49 ± 0.04 kg of grass DM); to do so pigs walk 3.9 ± 0.18 km in 369.0 ± 7.8 min of activity which happens at an average temperature of 7.6 ± 0.2 °C. The daily expenditure of ingested energy is divided as follows: 13.8 ± 0.18 MJ for the resting metabolism (54.1% ± 0.44); 5.5 ± 0.14 MJ for thermoregulation (21.5% ± 0.29); 6.3 ± 0.15 MJ for grazing, divided in displacement (8.0% ± 0.32) and standing (16.4% ± 0.25) during the activity. The total energy cost is therefore 25.7 ± 0.38 MJ ME, which equals 51.2% ± 2.71 of the ingested ME. ME available for production was 30.7 ± 2.33 MJ per pig and day, equivalent to 0.8 ± 0.06 MJ/kg $LW^{0.75}$ per day. The total heat losses were 31.8 ± 0.59 MJ per pig and day. The corresponding ratios are: 253.0 ± 13.05 g/kg DM for gain/feed, 15.3 ± 0.79 g/MJ for gain/ME intake and 1.4 ± 0.06 MJ/kg $LW^{0.75}$. There are not significant differences between both sexes.

With an average daily weight gain of 0.79 ± 0.03 kg, the conversion rate of the ME consumed as grass and acorns is 56.4 ± 2.34 MJ ME (corresponding to 4.0 ± 0.29 Kg kernel DM and 0.7 ± 0.08 kg of grass DM). To ingest that amount of energy pigs have to use 10.5 ± 0.75 kg of entire acorns to shell these. Bearing in mind that the annual production of acorns of an average adult evergreen oak (*Q. ilex rotundifolia*) acorn production is very close to this amount, it could be established that pig feed conversion rate (FCR) for acorn equals the total acorn production from one adult tree. So stocking rate may be estimated by dividing the number of adult oaks of a *dehesa* by the expected weight gain; and it could be established that stocking rate should be <1pig/ha of *dehesa* to gain the minimum standard of 46 kg only grazing natural resources.

1. Introduction

The traditional husbandry system of the Iberian pig in the *dehesa* (cleared Mediterranean forest like savannah) is linked to the sustained use of the pasturelands, finishing pigs during the acorn mast-feeding. Rodríguez-Estévez et al. (2009a) suggest a daily DM intake of 3.1–3.6 kg acorn kernel and 0.38–0.49 kg grass, which is achieved thanks to the functional characteristics of this breed as well as its ability to select and shell acorns (Aparicio Macarro, 1964).

This system is of a great interest due to the differentiating characteristics it provides to the carcasses and the products derived from them (e.g. healthy fatty acid profile). As a

* Corresponding author. Tel.: +34 957218083.
E-mail address: pa2roesv@uco.es (V. Rodríguez-Estévez).

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consequence the meat of Iberian pigs is in great demand, and pigs fattened under the traditional system fetch prices up to 160% higher than conventionally raised animals, and dry cured hams fetch between 350 and 500% higher (FAO, 2007). Indeed, the main constraint to further increasing the output of these products is not lack of demand, but the limited range of the breed's traditional habitat.

When fattening pigs in the *dehesa*, acorns are the most limiting resource during the *montanera*, because unlike grass, their supply is not continually renewed. Therefore the stocking rate for the *montanera* season is based on estimates of the acorn production (Rodríguez-Estévez et al., 2007a, 2008a). The feed conversion rate (FCR) of the acorns is a very important aspect of the sustained use of the *dehesa.* Based on estimates, different authors suggest FCRs fluctuating between 8 and 12 kg of acorns (Montoya, 1993).

Knowledge of the FCR is key to establishing the stocking rate for the *montanera* season to ensure that the pigs can meet the requirements of the current Quality Standards for the Iberian Pig (MAPA, 2007). They need to fatten by at least 46 kg to reach the commercial slaughter weight (≥161 kg of LW) exclusively with natural resources consumed during at least 2 months of grazing.

The FCR depends on the characteristics of the diet, the energy expenditure caused by the search for food, its consumption and the average daily weight gain (ADG). This in turn is the result of factors related to the animal and its environment (Bastianelli and Sauvant, 1997).

The final purpose of this study, based on individual weighings and on direct observation of the grazing pigs, is a double one: on one hand to determine the FCR of acorns for Iberian pigs in field conditions as a way to assess an optimal stocking rate for a sustainable production; and on the other hand, to calculate the energy balance of the grazing pig based on published data on energy values of feed resources at the *dehesa* and the energy costs of physiological functions or activities of the animal.

2. Materials and methods

The experimental procedures and animal care conditions were approved by the Animal Experimentation Ethical Committee of the University of Córdoba, Spain.

2.1. Animals and handling

The study was conducted during the *montanera* of 2004–2005 at a *dehesa* of evergreen oaks (*Quercus ilex rotundifolia*) of 111 ha, with one commercial herd of 84 purebred Iberian fattening pigs (male and female) of the Silvela variety. Pigs were on average 12.1 ± 0.1 months of age and 110.2 ± 1.3 kg of LW at the start of the study and 157.9 ± 1.7 kg at the end, after 2 months. All pigs were castrated following the Spanish regulations, to work with the same kind of pigs of the traditional *montanera* system. The stocking rate (0.76 pigs/ha) was established with margins that guaranteed that the acorns would not run out before the fattening was completed (Rodríguez-Estévez et al., 2007a, 2008a).

The supply of resources was typical of a *dehesa*. Therefore the main food resources were acorns and grass; there were 8–14 kg of acorns per tree (Rodríguez-Estévez et al., 2007a) and the autumn production of grass was estimated at 200–500 kg of dry matter (DM) per hectare of the *dehesa* (Medina Blanco, 1956; Escribano and Pulido, 1998). No supplementary feed, salt or mineral supplements were offered during the experiment. The nutrient composition of the acorns and grass is shown in Table 1.

A familiarisation procedure was used to accustom the animals to having an observer very close to them as it has been described by Rodríguez-Estévez et al. (2009a).

2.2. Observation of individual behaviour during grazing

The observations of the grazing began after 9 days of adaptation, on the 10th day of the *montanera* and 6 days of observations and controls were carried out, one every 10 days.

Eleven observers helped with the observation of the pigs as it has been described by Rodríguez-Estévez et al. (2009a). On every observation day, the pigs were allowed to graze from 8.30 am to 18:30 while they were closely followed and their grazing activity and ingestive behaviour were continuously monitored. Both sexes were homogeneously distributed in the sampled population (32 males and 28 females).

With a pedometer and through a simulation of the movement the distance covered by each pig was measured (Somlo et al., 1991). The period of activity of each pig was recorded with a chronometer.

2.3. Survey of the amount of acorns consumed and oaks visited

The ingestion of an acorn is easily recognizable (Rodríguez-Estévez et al., 2009a). The Iberian pig does not utilise the entire acorn because it peels the acorn and discards the shell; however, as pigs waste an average of 18.9% of the acorn kernel when shelling acorns (Rodríguez-Estévez et al., 2009b), the ingestion of kernel has been reduced 18.9%.

In order to avoid the misapprehension that the ingested acorns would always have the same weight, thus ignoring the pigs' selective consumption (Rodríguez-Estévez et al., 2009c), it was decided that the acorns consumed under the *preferred oaks* (those under whose canopy ≥10 acorns were consumed) ought to be considered as representative of the daily acorn consumption, and so 300 g of samples were collected from under those trees. 20 acorns from those samples were

Table 1
Nutrient composition of acorn and grass (g/100 g DM)*; mean ± S.E (Rodríguez-Estévez et al., 2009a).

	Grass	Acorns[(1) (2)]
DM	24.05 ± 1.52	58.05 ± 1.28
Ash*	8.74 ± 0.79	1.94 ± 0.03
Crude protein*	15.73 ± 0.73	4.71 ± 0.21
Crude fibre*	21.28 ± 0.78	2.83 ± 0.09
Crude fat*	5.24 ± 0.41	10.22 ± 0.49
NFE*	64.83 ± 4.56	65.46 ± 0.62
ME (MJ/kg DM)[(3)]	10.27	17.6

[(1)] Acorn kernel makes on average 77% of the whole fruit.
[(2)] In Tables 2 and 3, the ratio DM:Wet basis for acorn kernel deviates from values of this table because in those ones DM content (g/100 g FM) is representative of acorns consumed in the 2004–2005 season.
[(3)] From García-Valverde et al. (2007).

individually weighed with and without shell before drying their endocarp, to calculate the average weight of acorns from each oak. Determination of the DM of samples, of acorn endocarps was carried out according to AOAC (2000) methods. Daily DM consumed was determined on the basis of the number of bites and the weight of DM per bite.

The average weight of the acorns consumed under the preferred oaks was also assumed for the remaining oaks. The weight of acorns consumed under the *preferred oaks* was calculated by multiplying the average acorn weight from each oak by the number of acorns consumed under it. In addition the weight of acorns consumed under the remaining oaks (<10 acorns/tree) was estimated from the weighted arithmetic mean of acorns from preferred oaks; considering that pigs tend to choose all the ingested acorns (Rodríguez-Estévez et al., 2009c).

2.4. Survey of grass intake

In a previous paper (Rodríguez-Estévez et al., 2009a), grass intake per bite was quantified in 1.4 ± 0.1 g wet basis and 0.26 ± 0.02 g DM. The bite size and weight of other resources have been disregarded because of their very low frequency and insignificant intake (Rodríguez-Estévez et al., 2009a).

2.5. Weighing of the pigs

To calculate ADG, all the pigs of the herd were weighed individually every fifteen days in the early morning, with no food intake since the previous evening. However, only the data corresponding to the pigs followed every observation day were used for the calculations. An electronic scale (precision of 100 g) was used for weighing. From the ADG of each period the weight of the pigs was calculated for each day of the observation period. The gain that occurred during the days which had passed between the weighing and the day of observation was added to the result of the previous weighing.

2.6. Relative energy calculations

Based on the following equations and considerations, the energy requirements for maintenance, expressed as metabolizable energy (ME), and the energetic cost of grazing were estimated as:

- energy required to meet basal (resting) metabolism needs: 349 kJ of the ME per kg $LW^{0.75}$ (López Bote et al., 2001).
- energy required to stand up: 0.29 kJ ME per kg $LW^{0.75}$ per min in standing position, as an average from data reported by Noblet et al. (1993) in adult sows and growing pigs. It was assumed that the pig is on foot the entire time it is active (not lying down) during the grazing period.
- energy required for thermoregulation: following ARC (1981) during grazing (equivalent to individually housed animals) increases in heat losses of 13–17 kJ ME per kg $LW^{0.75}$ per degree below an effective range of critical temperature of 20–23 °C are assumed; in pigs without activity (equivalent to animals housed in groups) 7 kJ ME per kg $LW^{0.75}$ per degree below an effective range of critical temperatures of 8–23 °C. It was assumed that the pig is alone all the time it is active (not lying down) during the 10 h of the grazing period, and that it is in a group during the time it is lying down, and during the other 14 h of the day. The energy needs and critical temperatures assumed are at the highest value of the mentioned ranges for pigs on grazing (21.3 (17/0.8) kJ ME per kg $LW^{0.75}$ per degree below 23 °C), because the Iberian pig is exposed to harsh meteorological conditions (wind, frost, rain, dew, etc.) while grazing during the *montanera* season and 8.8 (7/0.8) kJ ME/$LW^{0.75}$ per degree below 16 °C (average value of critical temperatures ranging between 8 and 23 °C) while remaining in group. Average daily temperatures were registered with a data logger. To calculate these needs for each pig, it has been considered the times of activity and resting along the day.
- energy required for movement: in level areas or with a negative slope 0.003 kJ of net energy (NE) per kg of LW per meter; in vertical 0.04 kJ NE per kg of LW per meter (Lachica and Aguilera, 2000). Considering the relief of the farm, we assumed that the pigs climbed 50 m, for every km they walked. For the transformation of the NE of movement to ME, an efficiency of 0.8 is assumed, similar to that of maintenance (López Bote et al., 2001).

The energy contents of the available food resources were taken from García–Valverde et al. (2007):17.60 MJ ME/kg of acorn kernel DM and 10.27 MJ ME/kg of grass DM.

ME available for production was obtained subtracting ME for maintenance and grazing to ME intake; and it has been assumed a value of 0.80 for kw to estimate the energy retained in body tissues.

2.7. Feed conversion rate calculations:

The FCR of the whole acorns, before peeling and shell discarding, was calculated by dividing the weight of the entire acorns daily consumed by the ADG.

2.8. Statistical analysis

All statistical analyses were done with the statistical package SPSS. Results are presented as a mean ± SE. To compare the FCR of both sexes, an analysis of variance was carried out following a Kolmogorov–Smirnov test to examine the existence of a normal distribution in the variables.

3. Results

3.1. Grazing activity and consumption of natural resources

Between 8:30 and 18:30 the pigs remained active 369 ± 7.8 min (61.5% of the observation time); in this period they walked a distance of 3.9 ± 0.18 km to eat 2.7 ± 0.22 kg of grass FM and to visit 96 ± 3.7 oaks, where they shelled 7.6 ± 0.33 kg of acorns FM to ingest 4.9 ± 0.22 kg acorn kernels FM (Table 2). There are not significant differences between both sexes.

Table 2
Daily ingestion of acorn kernels and grass by fattening Iberian pigs grazing in the dehesa over the montanera season, mean ± S.E. (N = 60).

	Wet basis (kg)	DM (kg)	ME (MJ)
Acorn kernel	4.9 ± 0.22	2.9 ± 0.13	51.3 ± 2.32
Grass	2.7 ± 0.23	0.5 ± 0.04	5.1 ± 0.43
Total	7.6 ± 0.31	3.4 ± 0.14	56.4 ± 2.34
Percent from kernel	66.9 ± 2.19	85.1 ± 1.32	90.4 ± 0.93
Percent from grass	33.1 ± 2.19	14.9 ± 1.32	9.6 ± 0.93

3.2. Energy balance

Average temperature was 7.6 ± 0.2 °C, which is below thermal neutrality; besides, during the study period, the environment temperature never approached or exceeded the upper critical temperature. Total ME intake was calculated to be 56.4 ± 2.34 MJ per pig and day (Table 2). Acorns contributed 90.4 ± 0.93% of the total supply of energy to the grazing pig. The calculated energy balance and the partition of energy expenditure in the grazing Iberian pig is shown in Table 3. Total energy costs in support of maintenance and physical activities related to grazing attained 25.7 ± 0.38 MJ ME per day, which represents 51.2 ± 2.71% of the ME ingested. There are not significant differences between both sexes.

ME available for production was 30.7 ± 2.33 MJ per pig and day, equivalent to 0.78 ± 0.06 MJ/kg $LW^{0.75}$ per day. Therefore, assuming kw = 0.8, the energy retained in body tissues would have been 24.6 ± 1.86 MJ per pig and day, which equals to 0.6 ± 0.05 MJ/kg $LW^{0.75}$; so total heat losses would have been 31.8 ± 0.59 MJ per pig and day.

3.3. Average daily gain and food conversion rate

ADG was found to be 0.79 ± 0.03 kg requiring a daily consumption of 56.4 ± 2.34 MJ ME provided by grass and acorns. So, the corresponding gain: feed and gain : ME intake ratios were: 253 ± 13.1 g/kg DM for gain/feed, 15.3 ± 0.79 g/MJ respectively. ME intake was on average 1.4 ± 0.06 MJ/kg $LW^{0.75}$. The FCR, expressed in terms of whole acorns required to achieve the reported growth rate, taking into account the contribution of grass, was 10.5 ± 0.75. There were not significant differences between sexes.

4. Discussion

Some small differences appear between acorn consumption values reported by Rodríguez-Estévez et al. (2009a) and the present results. However these deviations stem from recalculated values considering acorns consumed under the "preferred oaks" as representative of the daily acorn consumption instead of the "average acorn".

The energy ingestion of *montanera* diet is based on the high consumption of acorns. Availability of grass in the *dehesa* is highly variable, although its contribution to energy intake is always low. In the present study grass contributed 9.58% of the ME intake. Consequently, the presence of grass in the diet of the grazing pig was, when expressed in energy terms, six percentage units lower that found in the work by García-Valverde et al. (2007) who studied the nutritive value of main feed components of a *montanera* diet in Iberian pigs housed individually in a temperature-controlled room at 20 °C. However the main contribution of herbage to the overall nutrient supply would rely on the provision of amino acid N, particularly of lysine, a limiting factor in acorns, which may improve the N balance of the grazing pig (García-Valverde et al., 2007). In addition one has to keep in mind that several authors mention the pig has to eat grass to maintain its high acorn consumption, the provision of amino acids (Aparicio Macarro, 1964; López Bote et al., 2001; Nieto et al., 2002) and to benefit from its comparatively higher water content (Rodríguez-Estévez et al., 2008b, 2009a).

The distance walked every day is higher than the 1.5–3 km estimated by Aguilera and Nieto (2003); López Bote et al. (2001) also assumed that a horizontal movement of 3 km per day would suppose extreme mobility, though pigs can walk 5–8 km per day at the beginning of the *montanera* season. Buckner et al. (1998) state that pigs in extensive systems spend >25% of daylight hours grazing, even if their diet is based on concentrates. On the contrary, Guy et al. (1994) state that the activity of pigs in extensive systems does not have to differ from that of an intensive system; and Ewbank (1974) states that the activity depends on the hunger.

Edwards (2003) states that in Northern Europe the needs of pigs in extensive systems rise on average about 15% per year, to satisfy movement and thermoregulation. One has to keep in mind that the energetic expenditure for a pig to stay on foot is higher than for other species: It was found that it

Table 3
The estimated daily energy balance in the fattening Iberian pig grazing in the dehesa over the montanera season, mean ± S.E. (N = 60).

	Resting metabolism	Thermoregulation	Displacement (D)	Standing (S)	Grazing (D + S)	Total energy cost
ME required (MJ)	13.8 ± 0.18	5.5 ± 0.14	2.0 ± 0.08	4.2 ± 0.11	6.3 ± 0.15	25.7 ± 0.38
% MEI required for maintenance and physical activity	54.1 ± 0.44	21.5 ± 0.29	8.0 ± 0.32	16.4 ± 0.25	24.4 ± 0.42	100
% MEI	27.7 ± 1.51	11.2 ± 0.68	3.9 ± 0.21	8.4 ± 0.45	12.3 ± 0.60	51.2 ± 2.71
MEI = 56.4 ± 2.34 MJ						
MEI available for production = 30.7 ± 2.33 MJ						
ER in body tissues[(1)] = 24.6 ± 1.86 MJ						
ER as % MEI = 39.0 ± 2.17						
Total heat losses = 31.8 ± 0.59 MJ						

ME: metabolic energy.
MEI: total ME ingested.
ER: energy retained.
[(1)] Assuming kw = 0.8.

accounts for 15% of the ME consumed by sows in intensive systems, where they stay standing up for 241 min every day on average, and time spent eating is 14 min (Noblet et al., 1993). In the case of the *montanera* the energy required to meet extra costs for standing up equals $8.4 \pm 0.4\%$ of the ingested ME. Nevertheless the total energy expenditure to graze in the *dehesa* during the *montanera* season is very high, and it is of great interest to finish pigs as soon as possible to better use of natural resources. This can be best achieved with older Iberian pigs, with a higher ADG due to compensatory growth (Rodríguez-Estévez et al., 2007b).

The FCR contribution of the whole acorns (10.47 ± 0.75) is higher than the ratios of 6.67–8.85 suggested by López Bote et al. (2001), but similar to those of the 10, proposed by Aparicio Macarro (1964), 10.13, suggested by Rupérez Cuéllar (1957) for the end of the *montanera* season and 10.4, suggested by De Juana Sardón (cited by Laguna, 1998).

Knowing the FCR is key for establishing the stocking rate in the *montanera* season in order for pigs to be able to meet the requirements of the current quality standard for the Iberian Pig (MAPA, 2007). They need to be able to reach the slaughter weight (≥161 kg) only with natural resources consumed during grazing. Bearing in mind that an adult evergreen oak (*Q. ilex rotundifolia*) produces an average of 11 kg of acorns (Rodríguez-Estévez et al., 2007a), it could be assumed that a grazing Iberian pig requires the total annual production of acorns of an adult evergreen oak to obtain 1 kg weight gain. So stocking rate could be estimated dividing the number of adult oaks of a *dehesa* by the expected weight gain; a minimum of 46 kg according to quality standards (MAPA, 2007). The total number of adult trees of a *dehesa* could be calculated through GISs and zoning it by photointerpretation, to detect homogeneous areas of oak density and estimating the mean number of adult trees for each area by 5 random samplings using a scale pattern of 5 ha (Navarro Cerillo, 2004).

Quality standards establishes a stocking rate <2 pigs/ha of *dehesa* (MAPA, 2007). However, an average figure of 35 adult evergreen oaks/ha of *dehesa* has been reported (see Rodríguez-Estévez et al., 2007a). Accordingly, we claim that the stocking rate should be <1 pig/ha of *dehesa*, so that the minimum standard of 46 kg weight gain, based only on grazing natural resources, can be achieved under sustainable conditions.

5. Conclusion

This paper demonstrates a method to determine optimal stocking rates for sustainable and organic production. The observations of this study, in line with previous surveys, point out the inadequacy of accepting stocking rates higher than 1 fattening pig per hectare in the *dehesa* over the *montanera* season. Such high stocking rates would compromise a sustainable utilization of the resources of this Mediterranean ecosystem and would make impossible finishing Iberian pigs exclusively on fallen acorns and grass.

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