Intrinsic factors of acorns that influence the efficiency of their consumption by Iberian pigs

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A B S T R A C T

This paper deals with the efficiency of Iberian pigs when shelling acorns (Quercus ilex fruits) during the free ranging fattening period in the dehesa. The amount of kernel wasted per acorn (18.9 ± 1.2%) presents a high degree of variation influenced by differences in the morphology and size of the acorns. A positive correlation is observed between the weight of the waste kernel and the weight of the whole acorn, and the diameter. However, the percentage of waste correlates negatively with the weight of the kernel and its DM percentage, with the ratio kernel weight/shell weight, and with the percentage of kernel. On the other hand, the percentage of kernel wasted, correlates positively with the percentage of kernel. Oppositely to the traditional knowledge and opinion of farmers, it has been found that the bitterness of the kernel, assessed sensorially by humans, does not influence the amount of kernel wasted. The results indicate that it is possible to make predictions about wastage based on two simple linear regression models: dry kernel wasted = 0.404 × fresh shell weight (R² = 0.898; P = 0.000) and percentage of fresh kernel wasted = 0.893 × percentage of fresh shell (R² = 0.875; P = 0.000). It would be necessary to consider the kernel wastage in acorn conversion rate calculations. Also in the processes of acorn selection for tree repopulation in dehesas for pig finishing it would be convenient to consider the correlations between the characteristics of the acorns and the amount of kernel waste, using the regression models defined.

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1. Introduction

Iberian pigs used for the production of cured products have traditionally eaten the natural resources available in the dehesa (pastureland with evergreen oaks and cork trees) in the final fattening stage, which takes place during the montanera (mast-feeding) season. During this period, pigs only eat grass and fallen acorns; Rodríguez-Estévez et al. (2008a) suggest a daily DM intake of 3.1–3.6 kg of acorn kernel and 0.38–0.49 ± 0.04 kg of grass.

According to most authors (Carbonero et al., 2003; García et al., 2003; López-Carrasco et al., 2004), throughout the fruiting period, the characteristics and kernel composition for acorns from the evergreen oak (Q. ilex rotundifolia) remain constant for a tree. Furthermore Carbonero et al. (2002) did not detect size differences in crown position. Acorn kernel is very easy for the pigs to digest (Torrent et al., 1961; Varela et al., 1965; Nieto et al., 2002), but the shell has no nutritional value. However, Iberian pigs are capable of shelling acorns and consuming only the kernel, discarding the shell (Aparicio Macarro, 1964; Laguna Sanz, 1998). However, a certain amount of the kernel is wasted. Waste is defined as the amount of kernel that, once in the mouth of the pig, is spat out onto the ground because it is stuck to the shell or for other reasons.

Since the pigs do not move whilst they are shelling and chewing the acorns, the remaining shell and kernel are dropped around the point of consumption (Rodríguez-Estévez et al., 2007). Hence, once the ratio between the weight of the shell and the weight of the acorn has been established, based on the weight of the present shells, the amount of acorn (as well as kernel) consumed can be established and the efficiency of the pigs when shelling acorns can be calculated based on the leftover kernel found at the point of consumption.
The aim of this paper is to quantify the kernel wastage and to study if the characteristics of acorns could have any influence on the peeling efficiency of the Iberian pigs.

2. Materials and methods

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

2.1. Animals and handling

The study was performed using a herd of 86 Iberian pigs castrated. During 30 d, since October first, the flock grazed in an adaptation enclosure of 10 ha of dehesa beside the experimental paddock, receiving a daily commercial feed ration (500 g per head and day).

Pigs aged 13 ± 0.5 mo and with an average weight of 110 ± 2.4 kg of BW when they were put out to graze on fodder (on first November), with no supplementary feed, in a dehesa containing evergreen oaks (Q. ilex rotundifolia) (27 ± 0.8 adult trees/ha), located in Fuenteobejuna (Sierra Morena, Cordoba, Spain).

2.2. Sampling the oak trees and recording the acorns consumed

Sampling was done 9 d after the pigs had been put in the experimental paddock.

Samples of acorns and waste of their consumption (wasted kernel and shells) were gathered from beneath the canopy of 40 non-adjacent evergreen oaks (there were at least two trees between one sampling tree and another), located on a strip of land approximately 30 m wide.

Under each of these trees, approximately 300 g of acorns (≈ 50 acorns) were randomly collected. From each tree a subsample of 20 acorns was and subjected to the following measurements were taken: length (l), maximum diameter (D), L/D ratio, fresh acorn weight, fresh kernel weight and fresh shell weight. Once these acorns were weighed, they were dried at a temperature of 103 °C with forced ventilation for 24 h and then weighed to obtain the dried weights of the kernel (KD) and the shell (SD).

Using another sample of the acorns from each oak tree, which had been conveniently peeled and chopped, a sensorial analysis was performed in a tasting room in accordance with the procedure defined by Costell (2002), by 4 trained tasters, who classified the acorns into one of three categories: 0 = no bitter (“sweet”); 1 = few bitter and 2 = bitter.

Also under each of these trees, using a 1 m × 1 m frame placed randomly, all the shell remains (SR) and kernel remains (KR) inside the frame were collected. These remains (SR and KR) present were dried and weighed, obtaining the dried weight of the shell remains (SRD) and kernel remains (KRD) respectively, and these values were used in this study to avoid possible variations in weight owing to a loss of moisture in the remains that had been exposed to the elements.

The number of acorns consumed (NA) per square metre was determined using the expression NA = SRD/SD; the dried waste kernel per acorn consumed (WK) was calculated as WK = KRD/NA and the percentage of dried kernel wasted (PKW) can be determined as PKW = WK × 100/KD.

2.3. Statistical analysis

The statistical software package SPPS© was used for statistical analysis. The bivariate correlations between the different factors that might be linked with the characteristics of the acorns and their waste were calculated using Pearson’s coefficients, using the averages per tree as the input data. In order to compare waste between the three categories of bitterness defined, Tukey’s HSD multiple comparison test was used (α = 0.05). In order to establish a prediction model for
kernel waste, the variables that had displayed a significant Pearson coefficient with waste were used, following the stepwise method, introducing or eliminating variables from the model depending on the significance (probability) of the F value or the F value itself (criterion: F probability ≤0.05 for entry, F probability ≥0.1 for removal), until the model was obtained with the best fit.

3. Results

3.1. Characteristics of the acorns

On average, acorns in this experimental field measure 37 ± 0.5 mm (range: 28.8 to 41.6) in length and the greatest transversal diameter is 16.3 ± 0.3 mm (12.8 to 21.4), which gives an average length to diameter ratio of 2.3 ± 0.1 (between 1.8 and 3.1). Besides, these acorns weigh 6.3 g (3.18 to 13.1) of which 1.3 g correspond to shell and 5.0 g to kernel (Table 1 and Fig. 1).

Classification into the pre-established categories of bitterness revealed that the proportion of no bitter to bitter acorns was the same (37.5%) and that 25% acorns were few bitter. Besides the test HSD of Tukey did not show any significant difference between bitterness categories when comparing acorn size and weight (Table 2).

Table 3 shows that, during 10 d grazing, the pigs consumed an average of 26.1 acorns/m² of canopy cover, with a high variation coefficient. During this period, waste kernel accounted for 19%, which represents 0.53 ± 0.04 g per acorn consumed. As indicated by the variation coefficients, the amount of kernel wasted varied a great deal, between 6.0 and 33.9%, which represents between 0.2 and 1.2 g of kernel DM per acorn.

3.2. Relationship between the characteristics of the acorn and the percentage of waste

Table 4 shows the Pearson coefficients for the bivariate correlations between the characteristics of the acorns and their waste. The variables that displayed the highest correla-

<table>
<thead>
<tr>
<th>Bitterness category</th>
<th>Whole acorn (g)</th>
<th>Dry kernel (g)</th>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
<th>Length/Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 = no bitter</td>
<td>6.0 ± 0.4</td>
<td>2.7 ± 0.2</td>
<td>37.0 ± 1.0</td>
<td>16.2 ± 0.5</td>
<td>2.3 ± 0.1</td>
</tr>
<tr>
<td>1 = few bitter</td>
<td>6.9 ± 0.7</td>
<td>3.6 ± 0.4</td>
<td>37.5 ± 0.9</td>
<td>16.5 ± 0.6</td>
<td>2.3 ± 0.1</td>
</tr>
<tr>
<td>2 = bitter</td>
<td>6.3 ± 0.5</td>
<td>2.9 ± 0.2</td>
<td>36.7 ± 0.9</td>
<td>16.3 ± 0.4</td>
<td>2.3 ± 0.1</td>
</tr>
</tbody>
</table>

Table 5

<table>
<thead>
<tr>
<th>Bitterness</th>
<th>Number of acorns available</th>
<th>Number of corresponding acorns consumed</th>
<th>Mean ± SE (CV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 = no bitter</td>
<td>26.11 ± 2.59 (0.63)</td>
<td>73.56 ± 6.71 (0.58)</td>
<td>17.76 ± 1.07 (0.38)</td>
</tr>
<tr>
<td>1 = few bitter</td>
<td>0.58 ± 0.05 (0.33)</td>
<td>0.46 ± 0.06 (0.43)</td>
<td>0.54 ± 0.07 (0.52)</td>
</tr>
<tr>
<td>2 = bitter</td>
<td>22.3 ± 1.35 (0.23)a</td>
<td>14.47 ± 2.56 (0.56)b</td>
<td>18.58 ± 2.03 (0.42)ab</td>
</tr>
</tbody>
</table>

Within a column, means without a common superscript letter differ (P<0.05).

** Correlation is significant at 0.01 (bilateral).
* Correlation is significant at 0.05 (bilateral).

Table 4 Pearson’s correlation matrix of the average acorn variables studied to explain fresh or dry kernel waste.

<table>
<thead>
<tr>
<th></th>
<th>Whole F acorn weight</th>
<th>F shell weight</th>
<th>D shell weight</th>
<th>DM % in the shell</th>
<th>F kernel weight</th>
<th>D kernel weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>F kernel waste %</td>
<td>−0.272</td>
<td>0.079</td>
<td>0.11</td>
<td>0.143</td>
<td>−0.33**</td>
<td>−0.426**</td>
</tr>
<tr>
<td>D kernel waste %</td>
<td>0.475**</td>
<td>0.477**</td>
<td>0.41**</td>
<td>0.038</td>
<td>0.439**</td>
<td>0.381(*)</td>
</tr>
<tr>
<td>DM % in the kernel</td>
<td>Number of acorns consumed/ m²</td>
<td>Number of acorns consumed/ m²</td>
<td>F kernel waste %</td>
<td>D kernel waste %</td>
<td>Length</td>
<td>Diameter</td>
</tr>
<tr>
<td>F kernel waste %</td>
<td>−0.438**</td>
<td>−0.186</td>
<td>1</td>
<td>0.598**</td>
<td>−0.126</td>
<td>−0.162</td>
</tr>
<tr>
<td>D kernel waste %</td>
<td>−0.071</td>
<td>−0.37*</td>
<td>0.598**</td>
<td>1</td>
<td>0.177</td>
<td>0.457**</td>
</tr>
<tr>
<td>Length/Diameter</td>
<td>F kernel/ F shell</td>
<td>D kernel/ D shell</td>
<td>F shell %</td>
<td>F kernel %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F kernel waste %</td>
<td>0.078</td>
<td>−0.475**</td>
<td>−0.529**</td>
<td>0.496**</td>
<td>−0.494**</td>
<td></td>
</tr>
<tr>
<td>D kernel waste %</td>
<td>−0.249</td>
<td>0.031</td>
<td>−0.122</td>
<td>−0.063</td>
<td>0.065</td>
<td></td>
</tr>
</tbody>
</table>

Notation: F, fresh; D, dried.

** Correlation is significant at 0.01 (bilateral).
* Correlation is significant at 0.05 (bilateral).

Table 3 Descriptive statistics of the kernel and shell remains (DM) found and the number of corresponding acorns consumed.

<table>
<thead>
<tr>
<th>Fresh basis</th>
<th>Dry basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of acorns consumed/m²</td>
<td>Kernel available in the acorns (g/m²)</td>
</tr>
<tr>
<td>26.11 ± 2.59 (0.63)</td>
<td>73.56 ± 6.71 (0.58)</td>
</tr>
</tbody>
</table>

X ± SE (CV).
By other side the linear regression models that offer the best fit to explain the percentage of kernel wasted are showed in Table 6. Although there are models with a higher value for $R^2$, the simplest model was thought to be of greater interest, in which the explanatory variable is percentage of shell.

### 4. Discussion

#### 4.1. Characteristics of the acorns

According to other authors, acorns from the evergreen oak (*Q. ilex rotundifolia*) come in a wide variety of shapes, sizes and compositions among different trees (Ramírez Lozano and Gómez Castro, 1982; Rodríguez-Estévez et al., 2008b). However, when studying acorns in a nearby area (Valle de Los Pedroches, Cordoba), Fernández et al. (2004) found similar average acorn weights to ones from this experimental field. Besides, the shell percentage is in accordance with the 18–20.3% reported by Mazuelos Vela et al. (1966).

The high variation coefficient of the average number of consumed acorns/m² of canopy cover can be explained by the mentioned variety of acorns, the varying availability of acorns under the canopy, whether they were appetising to the pigs and by the selections made by the animals (Rodriguez-Estévez et al., 2008c).

In spite of the amount of kernel wasted, pigs have to peel the acorns because the shell is not broken down either by the enzymes in the small intestine or by fermentation in the large intestine (Nieto et al., 2002) owing to the levels of tannin and lignin present, which make up 8.5 and 30.4% of the shell’s DM, respectively (Morales et al., 2002). These tannins have a negative affect on digestibility, especially of proteins and amino acids, which according to Aparicio Macarro (1964) and Nieto et al. (2002), are in themselves the main limiting factor of the pigs’ diet during the mast-feeding period.

#### 4.2. Relationship between the characteristics of the acorn and the percentage of waste

The more kernel an acorn has, the more kernel will be wasted; but the more kernel an acorn has and the dryer that kernel is, the less percentage of kernel is wasted. The real consumption of kernel depends on the weight of the acorn, the weight of the shell and the weight of the kernel wasted (Fig. 1).

It seems evident that the amount of wasted kernel that is discarded because it is stuck to the shell (in other words, for mechanical reasons) might be linked to the size of the acorn — defined by its weight – or to the relative amounts of kernel and shell or the ratio between both which, to a certain extent, is defined by the length and diameter of the acorn, or their ratio, which establishes the acorn’s degree of sphericity. Similarly, the amount of moisture in an acorn might affect the ease with which the kernel comes away from the shell and which can therefore remain in the mouth.

The bivariate correlation coefficients between the characteristics of the acorns and their waste could be low (Table 3) because kernel waste does not appear to be the result of an isolated variable.

In contrast, the flavour of the kernel may determine how appetising it is to the pigs and their chewing efficiency. In this sense the traditional understanding of pig farmers maintains that pigs prefer larger and sweeter or no bitter acorns (Acosta et al., 2001); in other words, its bitterness or no bitterness, from a human’s perspective (Acosta et al., 2001), might be responsible for how appetising acorns from a certain tree are to pigs. However the result found is contrary to expectation based on the traditional farmer’s knowledge; the level of bitterness, assessed sensorially by humans, did not seem to have a direct influence on the efficient use of the kernel, since the pigs make better use of acorns with an intermediate bitterness.

Other authors have also recorded a preference towards larger acorns (García et al., 2003). If, as Aran (1946) claims, pigs waste acorn kernel for reasons of preference, the acorns that have the least amount of waste should be the largest (length and diameter), heaviest and sweetest ones. On the contrary, there is a positive correlation between the amount of kernel wasted and the weight of the whole acorn ($P<0.01$) and its diameter ($P<0.01$). However, there is a negative correlation between the percentage of kernel wasted and the weight of the dried kernel ($P<0.01$) and the weight of the fresh kernel ($P<0.05$) (Table 3).

Aparicio Macarro (1964) indicates that Iberian pigs leave the kernel from the distal end of the acorn. According to this assertion, more oval shaped acorns (long and narrow), with a higher length/diameter ratio, should display a higher percentage of waste; however, this study found no significant correlations in this respect (Table 3).

The variables that displayed the highest correlation with waste were those related to the weight of the kernel and its percentage of DM. The more kernel an acorn has, the more kernel will be wasted; but the more kernel an acorn has and the dryer that kernel is, the less percentage of kernel is wasted (Table 3).

The results confirm that: given the kernel is wasted when the shell is spat out, the greater the proportion of shell, the more kernel will stick to it; and also that the less moisture there is in the kernel, the more easily it will come away from the shell. Hence, the highest and most significant bivariate correlations found correspond to the correlation between the amount of dried kernel wasted and the ratio between dried kernel and dried shell.

According with the obtained results, choosing the larger acorns pigs would be more efficient when shelling acorns. This could be enough to explain why pigs prefer acorns with higher DM kernel percentage at the beginning of the *montanera* and also why they always prefer the heaviest acorns (Rodriguez-Estévez et al., 2008c). Besides, this selective consumption is in accordance with Aparicio Macarro (1964), Vázquez (1998), Acosta et al., (2001) and García et al. (2003) and goes along.

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**Table 6**

Linear regression models and main statistics for the percentage of waste kernel.

<table>
<thead>
<tr>
<th>Models</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of waste $K = 0.89 \times \text{Percentage of F S}$</td>
<td>0.90***</td>
</tr>
<tr>
<td>Percentage of waste $K = -1.86 \times \text{F K weight} - 0.29 \times \text{S}$</td>
<td>0.92***</td>
</tr>
<tr>
<td>DM percentage $= 2.16 \times \text{Length} + 6.02 \times \text{Diameter} + 32.12 \times \text{Length/diameter} - 0.59 \times \text{F K percentage}$</td>
<td>0.90***</td>
</tr>
<tr>
<td>Percentage of waste kernel $= -0.38 \times \text{Shell DM} + 0.91 \times \text{F shell}$</td>
<td>0.91***</td>
</tr>
<tr>
<td>Percentage of waste $K = -0.31 \times \text{K DM} + 2.74 \times \text{F K/F S} + 1.26 \times \text{F S}$</td>
<td>0.91***</td>
</tr>
</tbody>
</table>

Notation: F, fresh; D, dried; DM, dry matter %; K, kernel; S, shell.

*** $P<0.001$. 

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When studying acorns in a nearby area (Valle de Los Pedroches, Cordoba), Fernández et al. (2004) found similar average acorn weights to ones from this experimental field. Besides, the shell percentage is in accordance with the 18–20.3% reported by Mazuelos Vela et al. (1966).
with the theory of *Optimal Foraging* (Emlen, 1966), which states that animals try to maximise their net rate of energy intake per unit time through the selection of their food intake.

The negative correlation found between the amount of kernel wasted and the number of acorns consumed/m² might be indicative of the relationship between waste and preference reported signalled by Aran (1946). However, bearing in mind the theory of *Optimal Foraging* (Emlen, 1966), consumption (appetising qualities) might be linked with abundance of supply. On the other hand, according to the perceptions of certain pig farmers, when there are lots of acorns under the canopy of a tree, the pigs spoil and waste many of them (Acosta et al., 2001); although this aspect has not been studied here. Furthermore, as long as there are more acorns available, the pigs tend to reject what has been left over from other acorns and any split acorns (Aparicio Macaro, 1964). However, the quantitative importance of this waste led to the traditional practice – once all the acorns in a plot of land had been finished and the fattened pigs had been taken out of this area – of bringing in young pigs to use up the leftovers and the rejected acorns (Laguna Sanz, 1998; Acosta et al., 2001). Finishing pigs could be encouraged to feed on the remaining kernels complementing their diet with commercial feed when acorn mast has run out (this period of assistance feeding is called *recebo*).

5. Conclusion

The quantification of kernel waste necessarily leads us to review traditional estimations of conversion rate and daily consumption of acorns and acorn kernel by Iberian pigs. The real consumption of kernel depends on the weight of the acorn, the weight of the shell and the weight of the kernel wasted. Bearing in mind that the amount of acorns is the most limiting factor in the montanera traditional fattening system, grazing should be organised by plots of land, so that once the supplies of whole or intact acorns from each plot have been exhausted, the younger pigs could be brought in earlier to use up the remaining kernel before it starts to deteriorate, especially in traditional extensive and organic farming systems, which use little supplementary feed.

Furthermore, the selection of animals used in extensive farming should be monitored in order to ensure that it takes into account functional characteristics, such as acorn shelling efficiency, which is currently not included in the Iberian pig breed standards or in the selection programmes. Moreover, it should also be borne in mind that the aims for selection and improvement in extensive farming systems are different to those in intensive systems, where animals are raised for commercial purposes. Moreover, it should also be borne in mind that the aims for selection and improvement in extensive farming systems are different to those pursued in intensive farming systems that do not use pasture grazing. The selection of more efficient breeds of pig could enhance the benefits of the montanera fattening system.

From an environmental perspective, the waste kernel is an easily accessible resource for other species of wild animals that consume acorns.

Finally, in the process of shrub clearing of initial Mediterranean forest by man to obtain a savannah-like ecosystem and in the process of acorn selection for tree repopulation intended for future grazing lands, the correlations between the characteristics of the acorns and the amount of waste should be considered, using the regression models defined in this paper. These practices would lead to a better use of natural resources.

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References


