NUTRITIVE VALUE OF CITRUS CO-PRODUCTS IN RABBIT FEEDING

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Abstract: Pulps from different citrus fruits are relevant agro-industrial co-products in the Mediterranean area in terms of amounts produced and availability. Moreover, part of the product is dehydrated, which increases its interest in monogastric species such as rabbits. Seventy eight samples from various Spanish producers using several types of fresh fruits (orange, tangerine, lemon and pomelo) and different processing methods of orange and tangerine samples (either fresh or dried after adding Ca(OH)\(_2\)) were analysed for their chemical composition and in vitro digestibility. Average dry matter (DM) contents of ash, neutral detergent fibre, acid detergent fibre, acid detergent lignin (ADL), soluble fibre, crude protein (CP), insoluble neutral and acid detergent CP, ether extract and gross energy were 49.0, 226, 139, 12.1, 213, 71.2, 13.1, 4.2, 30.5 g and 17.8 MJ/kg DM, respectively. Mean DM and CP in vitro digestibility were 86.7 and 95.6%, respectively. Digestible energy was estimated to be 15.1 MJ/kg DM. A high variability (coefficient of variation from 17% for CP to 60% for ADL) was observed among the samples for most of the traits studied, which was partially explained by the effects of type of fruit and processing. Lemon pulps had on average higher ash and fibre but lower sugar contents than the other pulps. Dehydration processes increased ash content (almost double than for fresh pulp) due to lime addition. As regards the current results, citrus pulp has potential for use in rabbit diets as a source of energy and soluble fibre.

Key Words: citrus pulp, type of fruit, processing, nutritive value, rabbits.

INTRODUCTION

The utilisation of agro-industrial co-products as animal feeds can be expected to have a positive economic impact and a reduction of the environmental burden. Citrus production is a major sector worldwide, covering a relatively stable surface of almost 10 million hectares and output of roughly 150 million tons. From the different citrus fruits, orange (50% of total production) is the most important, followed by tangerines (30% of total), lemons (12%) and pomelo (8%). China and Brazil are the main producers, but countries in the Mediterranean area, and particularly Spain, are also relevant (Faostat, 2017).

An important part of citrus production is transformed. In Spain, around 20% of total citrus production is transformed (MAPAMA, 2017), while more than 50% is processed in large producers such as United States or Brazil (Braddock, 1999; USDA, 2016). Moreover, a part of the citrus pulp production is dehydrated, which facilitates its transport and inclusion in feed formulations. Pulps obtained from citrus processing are therefore relevant co-products in terms of amounts produced and availability. Accordingly, the use of citrus pulps is increasingly interesting as an energy source for ruminants, but also for some monogastric species such as rabbits.

The main operations for citrus juice extraction and pulp production are reviewed by Braddock (1999) and include extraction, finishing and centrifugation. Additionally, essential oils and essences may be recovered. Citrus pulp is
produced as a final by-product, and are composed of peels, seeds and fruit pulp. The amount of this by-product accounts for one half of the wet mass of the whole fruit, and can be dried to facilitate its transport and use. Lime (Ca[OH]₂) is normally added to aid the dehydration, which also requires an important energy input. Finally, the dehydrated citrus pulp is usually pelleted, adding in some cases citrus molasses to the lime before the drying operation. Citrus molasses are produced by concentration of some of the water and sugars mechanically recovered by pressing the residue before the dehydration.

The chemical composition of citrus pulp varies widely according to the type of fruit, growing conditions, ripeness, climate and the manufacturing process used (Martínez-Pascual, 1977; Bampidis and Robinson, 2006). According to several databases (INRA, 2004; Bampidis and Robinson, 2006; FEDNA, 2010; CVB, 2016; SIA, 2017 and Heuzé et al., 2017), citrus pulp is characterised by a high proportion of sugars, although the different sources vary in the proportion assigned to this component (from 20 to 40%). The concentration of insoluble (NDF) and soluble fibre (SF, mostly pectins) is also relevant, accounting for around 19 and 30%, respectively, as average. There is also a significant ash content (about 6.5%) with a high proportion of Ca but low in P. Instead, both the crude protein (CP) and the essential amino acid levels (especially methionine and total sulphur amino acids) are low (about 2.8 and 2.3% of the total CP content, respectively) compared to rabbit requirements (4.9 and 3.5% for growing rabbits; De Blas and Mateos, 2010).

The aim of the current study was to measure the nutrient composition and in vitro digestibility of different citrus pulp co-products obtained from commercial industries using different manufacturing procedures, in order to evaluate the potential nutritive value for rabbits.

**MATERIALS AND METHODS**

**Samples**

A total of 78 samples of citrus pulps were surveyed during the citrus harvest season 2015/2016. Samples were provided by different commercial citrus plants in Spain, considering various times of sampling during the production season and diverse types of fruits. Samples were collected from the industry either fresh or dried. Information on pulp dehydration was provided by the industries supplying the samples. The drying process consisted of adding lime at a variable proportion to enable partial mechanical dehydration and final heat drying at 135-155°C.

**Chemical analysis**

Fresh samples were frozen and freeze dried before analyses. All samples were ground to 1 mm pore size. Dry matter, ash, crude fibre and ether extract were determined using procedures 934.01, 942.05, 978.10 and 920.39, respectively, from AOAC (2000). Total N was measured by combustion, using Leco equipment (model FP-528, Leco Corporation, St. Joseph, MI, USA) and CP content was estimated as an N content 6.25 (AOAC procedure 986.06). Total sugars were analysed according to the method of Yemm and Willis (1954). Total dietary fibre (TDF) was measured following procedure 985.29 (AOAC, 2000). Neutral detergent fibre, acid detergent fibre and acid detergent lignin (NDF, ADF and ADL, respectively) were determined sequentially using the filter bag system (Ankom Technology Corp., Macedon, NY, USA) according to Mertens (2002), AOAC (2000; procedure 973.187) and Van Soest et al. (1991), using heat stable amylase (42FAA, Ankom Technology Corp., Macedon, NY, USA) and expressed without residual ash. The SF concentration was calculated by difference as TDF–NDF (Van Soest et al., 1991; Abad et al., 2013). This method was compared with others by Abad et al. (2013), tending to render a higher value of soluble fibre. Otherwise, a European Ring-Test performed using this estimation in several laboratories (Trocino et al., 2013) showed a high relation with digestive and health traits in rabbits, which is also supported by Gidenne (2015). Hemicelluloses and cellulose contents were estimated from the difference between NDFADF and ADFADL, respectively. The proportion of neutral and acid detergent insoluble CP (NDICP and ADICP, respectively) was determined following the standardised procedures of Licitra et al. (1996), by analysing the N content (combustion method) in the NDF and ADF residues, respectively. Calcium was determined by atomic absorption spectrophotometric and colorimetric methods (procedure 991.25, AOAC 2000). Gross energy concentration was measured in an isoperibolic bomb calorimeter (Parr 6400, Parr Instruments Co., Moline, IL, USA).
Citrus co-products for rabbits

In vitro analysis

From the 78 samples chemically analysed, a group of 33 was selected searching for a wide variation in SF, NDF and sugars concentrations, and were analysed for in vitro DM and CP digestibility in rabbits. In vitro analyses were performed following the method proposed by Ramos et al. (1992) based on that of Boisen et al. (1991), and using Ankom bags following the modification proposed by Abad et al. (2013). Samples, previously ground to 1 mm pore size, were weighed (0.5 g) into filter bags (Ankom Technology Corp., Macedon, NY, USA) and placed in a Daisy II incubator jar (3.5 L and 30 filter bags/jar). A magnetic rod, 25 mL of phosphate buffer (0.1 M, pH 6.0) and 10 mL of 0.2 M HCl solution were added for each bag (750 mL of phosphate buffer and 300 mL of HCl solution for each jar with 30 bags). The solutions were mixed carefully by gentle magnetic stirring, the pH was measured and then adjusted to pH 2 with 1 M HCl or 1 M NaOH solutions. Then, a 1 mL/bag (30 mL/jar) of fresh pepsin solution (25 mg of pepsin (pepsin from porcine, 2000 FIP-Units/g protein, Merck n 7190)/mL 0.2 M HCl) was added and mixed. The jar was closed and the samples incubated in an oven at 40°C for 1.5 h. After this incubation, 10 mL /bag (300 mL/jar) of fresh pancreatin solution (100 mg of pancreatin [pancreatin from porcine, grade VI]/mL phosphate buffer pH 6.8) was added, the jar closed and the samples incubated at 40°C for 3.5 h. After the second incubation, the pH was adjusted to 4.8 by adding acetic acid and the 0.5 mL/bag (15 mL/jar) of Viscozyme (Viscozyme 120 L, 120 FBG/G, Novo Nordisk) was added, mixed and incubated at 40°C for 16 h. The entire soluble residue was then removed and the bags were washed in the jar with water at 40°C 3 times and mixed carefully (the first one for 30 min at 40°C with agitation in the incubator), followed by rinsing with acetone to prevent adherence of any residue in the bags. Finally, the bags were dried at 103°C for 24 h. Two bags without any sample were used as blanks in each jar. In vitro DM digestibility (DMd) was calculated as:

$$\text{DMd} = \frac{W_3 - (W_1 \times C_1)}{W_2}$$

Where $W_1$ is the bag tare weight, $W_2$ is the dry sample weight, $W_3$ is the final oven dry weight of the bag after digestive process and $C_1$ is the blank bag correction (final oven dry weight of the blank bag after digestion/original blank bag weight). Additionally, the CP concentration was measured in the dry residue to determine the in vitro CP digestibility ($\text{CPd}_{inv}$).

Statistical analysis

The effects studied were analysed using the MIXED procedure from SAS (2008), considering the supplier as a random effect and type of fruit and its processing as main fixed effects. Interactions were not measured because the sample collection was not structured, as only orange and tangerine samples were available to study the effects of processing. Most of the dried samples (n=17) were obtained from one of the processing plants surveyed, and used to compare the effects of processing against fresh samples (n=15) from the same origin. The Tukey test was used for multiple mean comparisons among types of fruit. Proc CORR of SAS (2008) was performed to determine correlations among chemical variables. A stepwise regression analysis was used to predict the in vitro DM and CP digestibility from the chemical composition, using PROC REG of SAS (2008). The stepwise procedure only introduces variables in the model when they contribute to a significant improvement ($P<0.05$) in the estimation of the dependent variable.

RESULTS

The mean values for each analytical component and its variability (expressed from its range, standard deviation and coefficient of variation) for the whole set of data samples surveyed are presented in Table 1. The results indicate that sugars (40.8%), soluble fibre (21.3%) and neutral detergent fibre (NDF, 22.6%) were the main citrus pulp components, with a relevant variation among samples (CV=25-32%). Variability was even greater for other feed constituents such as ash, ADL or NDICP and ADICP, (CV=49.2-60.5). In contrast, GE content or in vitro digestibilities of DM and CP varied in a lesser range (CV=3-7%). The correlation matrix among the chemical components is shown in Table 2. Neither CP or ether extract (EE) contents were significantly correlated to any of the other components studied. Otherwise, there was a high negative relation between sugars and all the fibrous traits, especially for TDF ($r=-0.89$) and ADF ($r=-0.84$). Likewise, it can be
observed that SF was positively associated with several insoluble fibre traits, as CF and NDF. The correlation between total and soluble fibre contents was very high ($r=+0.79$).

The effects of type of fruit (orange, tangerine, lemon and pomelo) and processing type (fresh or dried+$\text{Ca(OH)}_2$) on the chemical composition and in vitro digestibility of DM and CP are presented in Table 3. All the dried samples in the survey corresponded to orange and tangerine. Accordingly, the effect of type of fruit was measured using only fresh samples. The results indicate that fresh lemon pulp had a lower content of sugars and GE together to a generally

Table 1: Mean and variability of the chemical composition (%DM) and in vitro digestibility (%) of 78 samples of citrus pulps.

<table>
<thead>
<tr>
<th>Traits</th>
<th>n</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>SD</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>78</td>
<td>4.90</td>
<td>3.0</td>
<td>20.3</td>
<td>2.88</td>
<td>58.8</td>
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<tr>
<td>Crude protein</td>
<td>78</td>
<td>7.12</td>
<td>5.12</td>
<td>11.2</td>
<td>1.2</td>
<td>16.9</td>
</tr>
<tr>
<td>Ether extract</td>
<td>78</td>
<td>3.05</td>
<td>1.0</td>
<td>8.3</td>
<td>1.4</td>
<td>46</td>
</tr>
<tr>
<td>Crude fibre</td>
<td>78</td>
<td>12.3</td>
<td>6.4</td>
<td>28.6</td>
<td>3.98</td>
<td>32.4</td>
</tr>
<tr>
<td>Neutral detergent fibre</td>
<td>78</td>
<td>22.6</td>
<td>11.8</td>
<td>43.1</td>
<td>5.8</td>
<td>25.7</td>
</tr>
<tr>
<td>Acid detergent fibre</td>
<td>78</td>
<td>13.9</td>
<td>8.3</td>
<td>23.2</td>
<td>3.0</td>
<td>21.6</td>
</tr>
<tr>
<td>Acid detergent lignin</td>
<td>78</td>
<td>1.21</td>
<td>0.34</td>
<td>5.18</td>
<td>0.72</td>
<td>60</td>
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<tr>
<td>Hemicelluloses</td>
<td>78</td>
<td>8.70</td>
<td>3.0</td>
<td>24.8</td>
<td>4.0</td>
<td>46</td>
</tr>
<tr>
<td>Cellulose</td>
<td>78</td>
<td>12.7</td>
<td>7.4</td>
<td>18.2</td>
<td>2.7</td>
<td>21.3</td>
</tr>
<tr>
<td>Total dietary fibre</td>
<td>78</td>
<td>43.9</td>
<td>22.3</td>
<td>70</td>
<td>9.2</td>
<td>21.1</td>
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<tr>
<td>Soluble fibre</td>
<td>78</td>
<td>21.3</td>
<td>6.8</td>
<td>42.2</td>
<td>6.8</td>
<td>32</td>
</tr>
<tr>
<td>NDICP</td>
<td>78</td>
<td>1.31</td>
<td>0.31</td>
<td>2.9</td>
<td>0.64</td>
<td>49.2</td>
</tr>
<tr>
<td>ADICP</td>
<td>78</td>
<td>0.42</td>
<td>0</td>
<td>1.07</td>
<td>0.24</td>
<td>60</td>
</tr>
<tr>
<td>Sugars</td>
<td>67</td>
<td>40.8</td>
<td>17.6</td>
<td>64.9</td>
<td>10.5</td>
<td>25.7</td>
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<tr>
<td>Gross energy (MJ/Kg DM)</td>
<td>78</td>
<td>17.8</td>
<td>15.6</td>
<td>19.2</td>
<td>0.6</td>
<td>3.37</td>
</tr>
<tr>
<td>DMd_{iv}</td>
<td>33</td>
<td>86.7</td>
<td>78.2</td>
<td>97.4</td>
<td>5.7</td>
<td>6.59</td>
</tr>
<tr>
<td>CPd_{iv}</td>
<td>10</td>
<td>95.6</td>
<td>89.4</td>
<td>97.7</td>
<td>3.1</td>
<td>3.3</td>
</tr>
</tbody>
</table>

NDICP: Neutral detergent insoluble crude protein; ADICP: Acid detergent insoluble crude protein; DMd_{iv}: Dry matter digestibility in vitro; CPd_{iv}: Crude protein digestibility in vitro.

Table 2: Correlation (Pearson’s coefficient) matrix\(^1\) among chemical composition in 78 samples of citrus pulps.

<table>
<thead>
<tr>
<th>Traits</th>
<th>CF</th>
<th>NDF</th>
<th>ADF</th>
<th>ADF</th>
<th>Hem</th>
<th>Cell</th>
<th>TDF</th>
<th>SF</th>
<th>CP</th>
<th>NDICP</th>
<th>ADICP</th>
<th>EE</th>
<th>Sugars</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDF</td>
<td>0.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>ADF</td>
<td>0.73</td>
<td>0.57</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>ADL</td>
<td>0.37</td>
<td>0.37</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hem</td>
<td>0.28</td>
<td>0.28</td>
<td>0.35</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Cell</td>
<td>0.71</td>
<td>0.71</td>
<td>0.97</td>
<td>0.29</td>
<td>0.40</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>TDF</td>
<td>0.69</td>
<td>0.69</td>
<td>0.81</td>
<td>0.49</td>
<td>0.36</td>
<td>0.76</td>
<td></td>
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<tr>
<td>SF</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.48</td>
<td>-0.24</td>
<td>0.37</td>
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<tr>
<td>CP</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
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<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
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<tr>
<td>NDICP</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>0.30</td>
<td>0.39</td>
<td>NS</td>
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<td>NS</td>
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<tr>
<td>ADICP</td>
<td>NS</td>
<td>NS</td>
<td>0.29</td>
<td>0.54</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>0.26</td>
<td>0.76</td>
<td></td>
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<tr>
<td>EE</td>
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<td>NS</td>
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<td>NS</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Sugars</td>
<td>-0.68</td>
<td>-0.67</td>
<td>-0.84</td>
<td>-0.54</td>
<td>-0.34</td>
<td>-0.81</td>
<td>-0.63</td>
<td>NS</td>
<td>NS</td>
<td>-0.26</td>
<td>-0.38</td>
<td>-0.23</td>
<td></td>
</tr>
<tr>
<td>GE</td>
<td>-0.42</td>
<td>-0.42</td>
<td>-0.28</td>
<td>NS</td>
<td>-0.27</td>
<td>-0.35</td>
<td>-0.25</td>
<td>0.47</td>
<td>0.28</td>
<td>NS</td>
<td>-0.23</td>
<td></td>
<td>-0.37</td>
</tr>
</tbody>
</table>

\(^1\)Only significant ($P<0.05$) correlation coefficients are shown.

CF: Crude fibre; CP: Crude protein; NDF: Neutral detergent fibre; ADF: Acid detergent fibre; ADL: Acid detergent lignin; Hem: Hemicellulose=NDF-ADF; Cell: Cellulose=ADF-ADL; TDF: Total dietary fibre; SF: Soluble fibre; NDICP: Neutral detergent insoluble crude protein; ADICP: Acid detergent insoluble crude protein; EE: Ether extract.
higher level of soluble and insoluble fibrous components than the other citrus pulps. Neither CP, NDICP, ADICP or EE concentrations were affected by type of fruit. Orange and tangerine pulps did not differ for any chemical constituent, so they were analysed together to test for the effects of processing. As shown in Table 3, the addition of Ca(OH)$_2$ before drying led to a decrease in sugar and GE concentration and to an increase of ash and some fibrous traits (ADF, ADL, NDICP and ADICP) compared to fresh samples.

In vitro digestibilities of DM (DM$_{iv}$) and CP (CP$_{iv}$) were high (respectively 86.7 and 95.6% on av.) with little variation among samples (standard deviation [SD]=5.86 and 3.44). A stepwise regression analysis, using as independent variables all the chemical traits measured, included only CF in the prediction equations of DM and CP in vitro digestibility:

- $DM_{iv}$(%)=$93.9 \pm 2.65$, standard error of mean (SEM)=$0.61(\pm 0.20)$ CF (n=33); $R^2=0.22$; $P=0.005$
- $CP_{iv}$(%)=$102.3(\pm 2.69)–0.67(\pm 0.023)$ CF (n=10); $R^2=0.52$; $P=0.02$

The regression equation derived by Villamide et al. (2009) was used to estimate the digestible energy (DE) content for rabbits of the citrus pulp samples from its measured DM$_{iv}$ and EE concentration:

$$DE (MJ/kg DM) = -1.51 + 0.180 \times DM_{iv}(\%)+0.32 \times EE (\%DM); R^2=0.69; residual standard deviation=0.46.$$  

The calculated values averaged 15.1 MJ/kg DM with a range between 13.2 and 17.0 MJ/kg DM.

**DISCUSSION**

The results of this study show that sugars are the main component in the citrus pulps studied, averaging 40.8% DM. This value is higher than most of those published in the literature (e.g. Bampidis and Robinson, 2006), which might be related to the systematic re-addition of molasses in most current Spanish commercial dried citrus pulp systems. The proportion of sugars was lower than average both in lemon and Ca(OH)$_2$ processed samples (28.8 and 41.0% DM, respectively). These changes were parallel to inversely higher contents in ADF concentration. A relatively low sugar and high ADF content in lemon pulp was also reported by Bampidis and Robinson (2006), whereas Martínez-Pascual and Fernández-Carmona (1980a) found that the proportion of ADF increased in direct relation to the amount of Ca(OH)$_2$ added to the pulp before drying.

The concentration of insoluble fibre (estimated by the NDF content) was also important (22.6% DM as average), with higher levels in lemon (31.2% DM) and pomelo (25.2% DM) samples and no significant differences among...
processing methods. The fibrous fraction tends to be poorly digested in rabbits (De Blas et al., 1992; Wiseman et al., 1992), due to the relatively short fermentation time in this species. However, the extension of fibre digestion is inversely related to the proportion of lignin (García et al., 2000; De Blas, 2013), so digestibility of NDF in citrus pulp should be appreciable because of its low degree of lignification (5.35% ADL on NDF, as average in the present study).

There is little previous information on the SF concentration in citrus pulps. The mean value obtained in the current data set was quite relevant (21.3% DM), with the highest value corresponding to the lemon pulp (25.5% DM). Soluble fibre has importance in rabbit nutrition, as several recent reviews on the use of beet and apple pulp in rabbit diets (De Blas, 2013; Trocino et al., 2013; Abad, 2015) have proven a high digestion efficiency for this component in rabbits, in addition to a positive effect on mortality prevention in growing animals. There is no former information published on the effects of the dietary inclusion of citrus pulp on these traits, but it might be expected that they would be similar to those observed for other sources of SF.

Citrus pulp does not promote gut motility, increasing retention time in the gut (Fraga et al., 1991), probably because of the low proportion of long-sized particles in this type of fibre and the presence of soluble fibre that forms gels in the digesta. Consequently, its inclusion in substitution for traditional sources of fibre (such as alfalfa hay) resulted in a decrease of feed intake and growing performance (Pérez de Ayala et al., 1991). Besides, this result may be related to the water soluble pectins contained in citrus pulp, which form gels in the gut, increasing the viscosity and promoting satiety. Citrus pulp also contains essential oils (such as limonin) characterised by a bitter taste. However, several studies reviewed by Heuzé et al. (2017) have not observed a decrease of rabbit performance at levels of inclusion up to 25%, when overall diets provided a sufficient level of long sized insoluble fibre. Similar conclusions have been obtained in recent work with growing pigs fed balanced diets containing 15 or 20% of citrus pulp (Antezana et al., 2015; Beccaccia et al., 2015, respectively).

Ash content in citrus pulp was variable, with the highest concentration (6.68% DM as average) observed for samples dried after Ca(OH)₂ addition and higher levels in lemon than in other fresh pulps. Consequently, GE concentration was lower in these samples than for the average of the data set studied. In addition, most of the total ash content (38%) corresponded to Ca, which can lead to problems when trying to control the dietary Ca:P ratio.

The CP content in citrus pulp was low and was not affected by treatments, averaging 7.12% DM and constituting a major limit for its inclusion in rabbit diets, as current CP recommendations in rabbit diets range from 16.7% DM in growing diets to 19.4% DM in breeding animals (De Blas and Mateos, 2010). For dried citrus pulp, the high temperatures (135-155°C) used might explain the higher values of NDICP, ADICP and ADL observed in this group of samples. As demonstrated by Garaú et al. (2007), temperature during dehydration modifies physico-chemical properties of dietary fibre, as well as the antioxidant effect of citrus by-products. Quantifying the effect of dehydration conditions on citrus pulp composition was outside the scope of this study, as samples were taken from industrial plants with specific conditions. However, technological alternatives considering lower temperatures could influence the chemical composition found in our study.

The DE content (15.1 MJ/kg DM) estimated in the current study from in vitro DM digestibility was relatively high. This prediction should be considered as a potential energy value, as it does not take into account the short fermentation time allowed in the rabbit digestion of a balanced diet. In this way, our estimation is close to the 15.9 MJ DE/kg DM determined by Martínez-Pascual and Fernández-Carmona (1980b); in this study, citrus pulp was given as the sole source of feed, which implied a low DM consumption (69.8 g/day), probably because of a high retention time in the gut that led to satiety and a lower intake. However, for diets used in practice with higher levels of long sized particles, the caecal retention time is normally shorter (Gidenne et al., 2008; De Blas, 2013), which ensures a faster rate of passage and thus a higher feed intake and better performance. Consequently, de Blas and Villamidé (1990) observed a decrease (from 13.1 to 11.3 MJ/kg DM) in the DE of citrus pulp for rabbits when increasing the ADF level in the basal diet from 13.5 to 24.6% DM. Accordingly, both INRA (2004) and FEDNA (2010) assigned to this ingredient a DE concentration of respectively 12.6 and 12.4 MJ/kg DM, lower than the value predicted in the present work (15.1 MJ/kg DM), but still higher than the recommendations of DE in diets for growing and breeding rabbits (11.3 and 11.9 MJ/kg DM, respectively; de Blas and Mateos, 2010).

Overall, commercial samples of citrus pulps currently available in Spain can be considered a good source of energy and soluble fibre for rabbit diets according to their analytical composition and in vitro determinations. However, its
inclusion in rabbit feeds is limited by its low supply of indigestible fibre and crude protein and by the high level of Ca in the case of Ca(OH)₂ processed samples. The main variation factors were the type of fruit (lemon being different from the others) and processing (dried or fresh). The dehydration method, particularly lime addition and dehydration temperature, could affect the composition of dried citrus pulp.

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