

Article

Feed Efficiency Can Be Sustained in Pigs Fed with Locally Produced Narbon Vetch (*Vicia narbonensis* L.)

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Abstract: There is an interest in replacing soybean meal with locally produced ingredients in livestock feeds. Narbon vetch is resistant to unfavorable climatic and soil conditions, common pests, and has a favorable nutritional profile. The effect of substitution of soybean meal with 0% (V0), 5% (V5), 10% (V10), and 20% (V20) inclusion of Narbon vetch on growth curve parameters, daily body weight gain (DBWG), daily feed intake (DFI), feed conversion efficiency (FCE), and residual feed intake (RFI) was investigated in 47 Duroc × Iberian barrows in 16 periods (a total of 125 d). DFI and DBWG were reduced ($p < 0.05$) up to four weeks after introduction of the novel feed in V20 and V10. Small, mostly nonsignificant differences existed between treatments in FCE and RFI. However, because of accumulative small differences in feed efficiency between the four diets, pigs in V0 reached the highest BW, and pigs in V20 reached the lowest BW on a similar feed intake. Economic implications of Narbon vetch inclusion depend on the extra amount of feed required and associated feed costs, and on the costs of additional days on-farm required to reach a given slaughter weight.

Keywords: Duroc × Iberian pigs; sustainable pig production; local feed crops; Narbon vetch; soybean replacement

1. Introduction

The exponential increase of the intercontinental trade of soybean has accompanied strong increases in pig production over the past few decades [1]. Soybean meal is a major ingredient in livestock feeds because of its high protein content (approximately 40%, up to 50%) with a suitable amino acid profile, relatively low water content, minimal variation in nutrient content, and antinutritional factors that are easily reduced or eliminated [2]. However, dependency on soybean meal as a protein source is a worldwide concern [3]; the focus of concern differs between stakeholders. Nongovernmental organizations (NGOs) emphasize the expansion of soybean production into the natural ecosystems of countries like Argentina and Brazil, resulting in deforestation, loss of biodiversity, soil decline, and displacement of small farmers and indigenous communities [4,5]. The European Parliament is particularly concerned with its heavy reliance on expensive soybean imports, comprising approximately 70% for agricultural protein products and >95% for soybean grains and meal [4,6]. Because of the notion of unsustainability of the heavy dependency on soybean meal imports and risk of trade disruptions, the European Parliament adopted a resolution in 2011 for stimulating on-farm animal feed production using mixed crops such as cereals and beans [5,7]. "Localization" of food and feed production is generally considered a vital component of a transition to a more sustainable and more just food system. Reliance on foods or feeds

produced near their point of consumption offers an array of economic, environmental, and social benefits, such as a reduced amount of energy used in their transport, improved economic viability of local farms and their communities, and decreased safety risks associated with decentralized production [8]. In poultry production, Leinonen and Kyriazakis [9] showed that the majority of all greenhouse gas emissions were caused by growing, processing, and transporting broiler, layer, and turkey feed. Therefore, using agricultural byproducts or locally produced protein sources such as beans, peas, rapeseed, and sunflower meal, is usually seen as a major opportunity to reduce the environmental impacts of simple nonruminant livestock production systems in Europe [9]. In addition, enhancing the EU protein crop production enlarges the possibilities for crop rotation, thus reducing the risk of crop diseases and stabilizing EU farmers' income [6]. Therefore, the cultivation of domestic protein plants and its research have been increasingly promoted in the EU [10].

In response, in 2013, the Focus Group on Protein Crops, involving 20 experts from 11 EU countries, investigated the question "How can the competitiveness [in terms of yield benchmarked to that of wheat and maize] of protein crops producers in the EU be improved?". The potential to increase productivity and protein content of several protein crops were published in their final report [11]. The report concludes that grain legumes like field peas, chickpeas, field and broad beans, and lupins are all to some extent interesting alternatives to soybean meal. They have high protein content, albeit distinctively lower than the wheat or maize benchmark, but have lower contents of the essential amino acids methionine and lysine. In addition, in some crops, antinutritional factors (ANFs) have been reduced in level due to breeding, which facilitates inclusion in animal feed. Yields of field peas and field and broad beans are high; however, they are generally sensitive to diseases and pests [6,11]. The central conclusion of the report is that the yield of local protein crops is currently too low for making cultivation attractive for European farmers, however, this can be stimulated through different aspects of innovation, including technical innovations on agronomy and breeding [6,11,12].

Since the quantity and quality of feed resources limit pig productive output, feeding diets based on local protein crops of suboptimal nutritional quality may result in reduced pig production efficiency. This is relevant since it may reduce profitability with negative implications to the economic sustainability of livestock farms [13]. There is, therefore, a need to evaluate the extent to which pigs are able to sustain production efficiency on locally produced protein crops [14]. *Vicia narbonensis L.*, or Narbon vetch, is an annual, local legume that is of interest since it is resistant to unfavorable climatic and soil conditions, resistant to common pests, and has a favorable nutritional profile [15]. The objective of this study was to investigate the implication of substituting different levels of soybean meal with Narbon vetch on production traits of Duroc × Iberian pigs. In the discussion section, we present a brief overview of the use of Narbon vetch in animal nutrition.

2. Materials and Methods

2.1. Animals and Management

A total of 48 Duroc × Iberian crossbred barrows, one pig per litter, were used in this experiment. One pig died for unknown reasons and was removed from the experiment. Pigs originated from a production farm belonging to San Jamón and were individually marked before the start of the experiment. The trial was conducted at the Porcine Testing Center of the Castile-Leon Agriculture Technology Institute (ITACyL) in Hontalbilla, Segovia, between the 28th of December 2018 and the 25th of April 2019 (125 days). Three animals per treatment were housed randomly and individually in one of 12 pens in one of 4 adjacent rooms in one barn. The experiment was conducted in one single trial. Each pen was equipped with a stainless-steel feeder and a nipple drinker. Feed and water were provided ad libitum during the entire experiment. All procedures followed the Spanish policy for the protection of animals used in research and other scientific purposes RD53 / 2013. The project was approved by the ITACyL Ethics Committee on Animal Experimentation, reference number 2018/37/CEEA.3.

2.2. Diet Formulations

Two diets were fed during the growing–finishing stage: a growth diet fed between d 0 and 53 of the trial (Table 1), and a fattening–finishing diet fed between d 54 and 125 of the trial (Table 2). Within each of the two diets, four compositions were formulated, including 0%, 5%, 10%, or 20% (V0, V5, V10, and V20, respectively) of Narbon vetch (*Vicia narbonensis* L.). The four diets were formulated by the agricultural cooperative AGROPAL (Palencia, Spain). Subsequently, a random sample of all formulated feeds was analyzed by the Porcine Testing Center (CPP). Diet composition, specified by the producer and analyzed by CPP, is given in Table 1; Table 2 for each of the two diets for each of the four treatments. Within each feeding phase, all four treatments were isocaloric; however, chemical analysis of the feed showed that the crude protein content varied slightly between 15% and 16% in the growing stage (Table 1), and between 14% and 15% in the finishing stage (Table 2). At the start of the experiment, animals were allocated randomly to one of the four dietary treatments assuring that initial body weights were balanced between treatments; no significant differences existed between the treatments in body weight at the start of the experiment.

Table 1. Diet formulations for the growing phase, including 0% (V0), 5% (V5), 10% (V10), and 20% Narbon vetch (V20).

Growing Period				
Composition Given by the Producer				
Ingredients (%)	V0	V5	V10	V20
Narbon vetch	0.00	5.00	10.00	20.00
Corn	14.30	12.00	9.92	5.40
Barley	30.50	29.50	28.60	26.60
Wheat	30.00	29.90	30.00	30.10
Corn DDGs	6.00	6.00	6.00	6.00
Rapeseed meal	4.00	4.00	4.00	4.00
Soybean meal 47	10.0	8.32	6.48	2.80
Lard	1.00	1.00	1.00	1.00
Soybean oil	1.00	1.00	1.00	1.00
Dicalcium phosphate	0.32	0.32	0.32	0.32
Calcium carbonate	1.36	1.36	1.36	1.36
Sodium chloride	0.45	0.45	0.45	0.45
L-lysine 50%	0.41	0.40	0.39	0.36
Premix ¹	0.50	0.50	0.50	0.50
Net energy (MJ/kg)	9.81	9.81	9.81	9.81
Analyzed Composition				
Moisture	11.50	12.0	11.2	11.5
Crude Protein	15.10	15.8	15.6	16.00
Ether extract	4.30	4.10	5.00	4.10
Crude fiber	4.30	4.60	5.00	4.70
Lysine	1.05	0.96	1.13	1.05
Methionine + Cysteine	0.38	0.44	0.49	0.44
Threonine	0.50	0.54	0.56	0.54
Tryptophan	0.32	0.35	0.31	0.29
GEC ²	0.00	0.08	0.11	0.19

¹For the vitamin and mineral premix, there was a nondisclosure agreement with the producer; ² γ -glutamyl-S-ethenyl-cysteine.

Table 2. Diet formulations for the fattening–finishing phase, including 0% (V0), 5% (V5), 10% (V10), and 20% Narbon vetch (V20).

Fattening–Finishing Period				
Composition Given by the Producer				
Ingredients (%)	V0	V5	V10	V20
Narbon vetch	0.00	5.00	10.00	20.00
Corn	25.00	25.00	25.00	25.00
Barley	23.00	19.60	15.80	15.80
Wheat	30.00	30.00	30.00	22.90
Corn DDGs	8.00	8.00	8.00	8.00
Rapeseed meal	0.00	1.00	2.20	3.00
Soybean meal 47	8.40	6.10	3.70	0.00
Lard	2.00	2.00	2.00	2.00
Soybean oil	0.00	0.00	0.00	0.00
Dicalcium phosphate	0.50	0.40	0.40	0.40
Calcium carbonate	1.40	1.40	1.40	1.40
Sodium chloride	0.50	0.50	0.50	0.50
L-lysine 50%	0.41	0.40	0.39	0.36
Premix ¹	0.50	0.50	0.50	0.50
Net energy (MJ/kg)	10.01	10.01	10.01	10.01
Analyzed Composition				
Moisture	11.90	11.40	11.70	12.20
Crude Protein	14.10	14.00	14.00	15.00
Ether extract	4.60	4.10	4.50	3.90
Crude fiber	2.90	3.40	4.30	4.00
Lysine	0.90	0.77	0.84	0.89
Methionine + Cysteine	0.42	0.43	0.42	0.46
Threonine	0.53	0.52	0.54	0.54
Tryptophan	0.28	0.23	0.24	0.24
GEC ²	0.00	0.10	0.13	0.24

¹For the vitamin and mineral premix, there was a nondisclosure agreement with the producer; ² γ -glutamyl-S-ethenyl-cysteine.

2.3. Body Weight Gain and Feed Intake

Age at the start of the evaluation was unknown for any of the 47 individuals but animals originated from the same birth-batch. Animals grew from an average body weight (BW) of 61.2 (SD 8.53) to 174 (SD 9.78) kg. Individual BW was measured at 14, 20, 32, 39, 46, 53, 60, 67, 74, 81, 95, 102, 109, 116, and 125 d on trial. Feed was given in excess daily. Leftover feed was weighed at the end of each period to calculate the total consumption for each of the 16 periods; all periods lasted 7 days, except period 1 (14 d), 3 (12 d), and 16 (9 d). Subsequently, average daily body weight gain (DBWG, kg/d) and average daily feed intake (DFI, kg/d) were calculated for each of the periods.

Modified Parks' [16] curves were fitted with the nonlinear function in SAS (proc NLIN) to individual data on BW against cumulative feed intake:

$$BW_t = A (1 - e^{-B(CFI_t + FI_0)}) \quad (1)$$

where BW_t = body weight of the individual (kg) at day t (d on trial); CFI_t = cumulative feed intake (kg) at day t (d on trial, on day 1 $CFI = 0$); A = mature (adult, asymptotic) body weight (kg); B = rate

of maturation of body weight with respect to feed intake (per kg); and FI_0 = a translation of Equation (1) along the x-axis to complete the description of growth (kg). A, B, and FI_0 are parameters to be estimated; only parameters A and B will be discussed. The modification of the Parks' curve involves the inclusion of FI_0 to avoid fixing the curve through any point [17]. Parameter estimates were only considered for individuals to which the convergence criterion was met.

A linear function by Parks [16] was used that related individual cumulative feed intake to day on trial to estimate daily feed intake in mature animals (MFI, kg/d). To ensure that cumulative intake increased linearly, MFI was calculated for measurements taken between periods 8 and 16:

$$CFI_t = Int + (MFI \times Day) \quad (2)$$

where CFI_t = cumulative feed intake of the animal (kg) at day t, Int = intercept, MFI = mature (maximum daily) feed intake (kg/d), and Day = d on trial (within period 8–16). Int and MFI are parameters to be estimated; only MFI will be discussed.

2.4. Feed Efficiency

Two methods were used to evaluate feed efficiency: 1) feed conversion efficiency (FCE), and 2) residual feed intake (RFI). Higher FCE and lower RFI imply a higher feed efficiency. FCE was calculated individually as $DBWG/DFI$ for each of the 16 periods. RFI is defined as the difference between the actual DFI and that predicted from a linear multiple regression of DFI on metabolic body weight ($BW^{0.75}$) and $DBWG$, and is therefore phenotypically independent of growth rate and size [18]. Following Rauw et al. [19], the equation used to estimate RFI was based on the following multiple linear regression of DFI on $BW^{0.75}$ and $DBWG$ including all measurements on all 12 individuals in V0 for all 16 periods:

$$DFI_i = b_0 + (b_1 \times BW_i^{0.75}) + (b_2 \times DBWG_i) + e_i \quad (3)$$

where DFI_i = average daily feed intake of individual i in V0 (kg/d); $BW_i^{0.75}$ = average metabolic body weight of individual i in V0 ($kg^{0.75}$); $DBWG_i$ = average daily body weight gain of individual i in V0 (kg/d); b_0 is the population intercept; b_1 and b_2 are the partial regression coefficients representing average maintenance requirements per kg metabolic BW and average feed requirements for $DBWG$, respectively; and e_{ijk} is the error term, which represents the RFI of individual i in V0, in kg/d. Metabolic BW was estimated as the average metabolic BW for the 16 periods. Subsequently, RFI was calculated for each individual in V0, V5, V10, and V20 for each of the 16 periods as:

$$RFI_{ip} = DFI_{ip} - \{b_0 + (b_1 \times BW_{ip}^{0.75}) + (b_2 \times DBWG_{ip})\} \quad (4)$$

where DFI_{ip} = average daily feed intake of individual i in period p (kg/d), $BW_{ip}^{0.75}$ = average metabolic body weight of individual i in period p ($kg^{0.75}$), and $DBWG_i$ = average daily body weight gain of individual i in period p (kg/d).

2.5. Statistical Analyses

The SAS program (SAS Institute, Cary, USA) was used for the statistical analyses of the individual repeated measurements $DBWG$, DFI , FCE , and RFI :

$$Y_{ijkl} = \mu + Period_i + Treatment_j + (Period \times Treatment)_{ij} + BW0_k + e_{ijkl} \quad (5)$$

where Y_{ijkl} = the phenotype measured on animal l; $Period_i$ = effect of period i (1 to 16); $Treatment_j$ = effect of dietary treatment j (fixed effect; V0, V5, V10, V20), and $(Period \times Treatment)_{ij}$ = the interaction effect of period i \times dietary treatment j; $BW0_k$ = the effect of body weight at the start of the experiment k (covariate effect); and $e_{ijkl} \sim NID(0, \delta^2e)$. Initially, the effect of room was also included in the model, but since this was not significant it was removed. Period was identified as the repeated effect in the model for each individual. Because FCE is a ratio, values were log-transformed for analysis. Least squares means (\pm s.e.m.) of log-transformed values were then back-transformed and presented. The following variance–covariance structures for repeated measures were evaluated to describe

individual observations on a trait-by-trait basis: Homogeneous Autoregressive(1) (AR(1)), Heterogeneous Autoregressive(1) (ARH(1)), Compound Symmetry (CS), Toeplitz (TOEP), and Unstructured (UN). The models included the random effect of the individual. Model choice was based on evaluation of fit statistics [the (corrected) Akaike's information criterion and the Sawa Bayesian information criterion]. Based on the fit statistics, DBWG and log-transformed FCE were analyzed with the ARH(1) model, DFI with the TOEP model, and RFI with the AR(1) model.

Parameters A, B, and MFI were analyzed with the following model:

$$Y_{ij} = \mu + \text{Treatment}_i + e_{ij} \quad (6)$$

where Y_{ij} = the phenotype measured on animal j and Treatment_i = effect of dietary treatment i (fixed effect; V0, V5, V10, V20); $e_{ij} \sim \text{NID}(0, \delta^2e)$. Initially, the effect of room was also included in the model, but since this was not significant it was removed. Partial Spearman correlation coefficients (of nontransformed values) between all traits were estimated after adjusting for the effect of treatment and BW0.

3. Results

Equation (1) converged in all but two animals. The curves fitted the data very well, as indicated by the goodness-of-fit, R^2 , of 99% to nearly 100%. Pigs in V10 and V20 were estimated to grow to a lower mature body weight, A, but were estimated to do so at a similar rate of maturation with respect to feed intake, B, than pigs in V0 and V5 (Table 3). MFI was reduced with an increased inclusion of Narbon vetch; however, this was not significant.

Table 3. Mature body weight (A) and rate of maturation with respect to feed intake (B) (Equation (1)), and mature feed intake (MFI; Equation (2)) in pigs fed 0% (V0), 5% (V5), 10% (V10), and 20% (V20) Narbon vetch.

	V0	V5	V10	V20
A	320 ^x (± 8.03)	316 ^x (± 8.03)	289 ^y (± 8.80)	292 ^y (± 8.39)
B	0.00123 ^x (± 0.0000852)	0.00118 ^x (± 0.0000852)	0.00139 ^x (± 0.0000933)	0.00121 ^x (± 0.0000889)
MFI	3.88 ^x (± 0.120)	3.74 ^x (± 0.120)	3.71 ^x (± 0.120)	3.62 ^x (± 0.126)

¹Values with different superscripts are significantly different ($p < 0.05$).

Body weight as a function of cumulative feed intake is presented in Figure 1 for each of the four dietary treatments. Figure 1 shows that at the end of the experiment, with increasing inclusion of Narbon vetch, pigs had eaten less feed and had reached a lower body weight.

After adjustment for the effect of treatment and initial body weight, results showed that pigs with higher DFI had higher DBWG ($r = 0.33$ to 0.71 , $p < 0.01$), pigs with higher DBWG had higher FCE ($r = 0.62$ to 0.93 , $p < 0.0001$), pigs with higher DFI had higher RFI ($r = 0.67$ to 0.92 , $p < 0.0001$), and pigs with higher FCE had lower RFI ($r = -0.30$ to -0.72 , $p < 0.05$). Equation (3) had an R^2 of 37%; the intercept (1.01 ± 0.261), and the contribution of $\text{BW}^{0.75}$ (0.0478 ± 0.00552) and DBWG (1.06 ± 0.143) to DFI were all significant ($p < 0.0001$). Trends in DBWG, DFI, FCE, and RFI are presented in Figure 2a–d. Note that periods lasted approximately one week each, with the exception of periods 1 and 3 which lasted approximately two weeks each. Figure 2a,b shows that, in several periods, pigs in V0 had highest DBWG and DFI, while pigs in V20 had lowest DBWG and DFI. In particular, DBWG is reduced after introduction of the novel feed (i.e., in periods 1 and 7) in pigs in V20 and to a lesser extent in pigs in V10. Differences between treatments in DBWG are greatly reduced and are in some cases no longer significant approximately 4 weeks after a change in diet (i.e., after periods 3 and 10). A similar trend can be seen for DFI; however, the depression after a diet change in DFI appears to persist a little longer than the depression in DBWG.

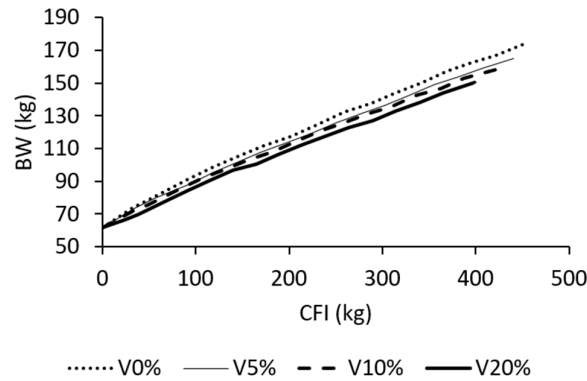


Figure 1. Body weight (BW) as a function of cumulative feed intake (CFI) in pigs fed a diet formulation with 0%, 5%, 10%, or 20% Narbon vetch (V0%, V5%, V10%, and V20%, respectively).

Figure 2c shows that, in general, any depression in DBWG is proportional to the depression in DFI, such that nearly no significant differences exist between treatments in FCE. FCE only dropped significantly in pigs in V20 in periods 1, 2, and 7. Differences between treatments in RFI were only significant in periods 2 and 10 (Figure 2d).

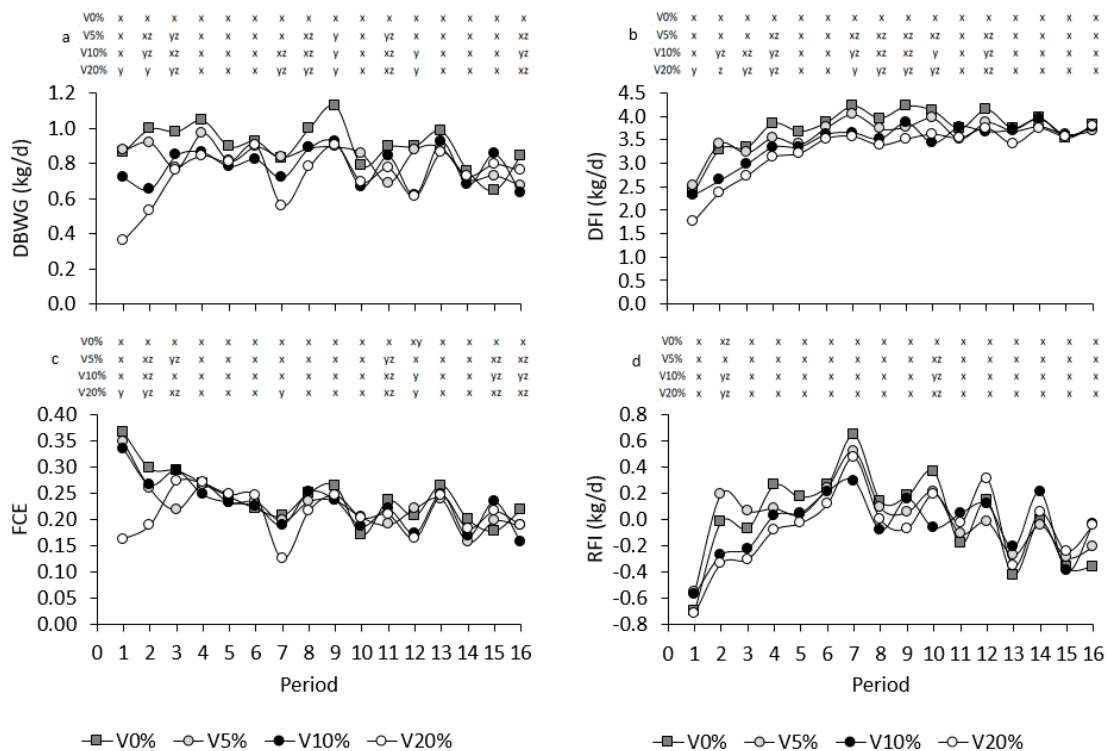


Figure 2. For each period: (a) daily body weight gain (DBWG); (b) daily feed intake (DFI); (c) feed conversion efficiency (FCE); and (d) residual feed intake (RFI) of pigs fed diets with 0% (V0%), 5% (V5%), 10% (V10%), and 20% (V20%) Narbon vetch.

4. Discussion

4.1. An Overview of Narbon Vetch in Animal Nutrition

Vicia narbonensis, or Narbon vetch, is a crop that originates from northwest Asia and is well adapted to the Mediterranean climate. Traditionally in Spain, it is marginally produced in Castilla La Mancha, Extremadura, and Andalucía [20]. It grows on neutral/alkaline soils with low to medium

rainfall conditions, and is adapted to both hot and cold temperatures [20–23]. Its production can vary between 470 kg/ha in poor conditions to 4000 kg/ha on deep and fertile soils with more abundant water provision or rainfall [20]. In those places where it is cultivated, it is preferred over faba beans (*Vicia faba* L.) for its major resistance to pests and diseases [24], and it appears that the crop is not damaged by rabbits and voles (personal communication by farmers). Francis et al. [25] reported that Narbon vetch has a protein content between 21% and 30%. An evaluation of new sources of vegetable protein that could reduce the high dependency on imported soy showed that two Narbon vetch varieties, ZU-154 and Icarda-2470, had 27% and 28% protein, 53% total carbohydrates, 3.4% and 3.5% ash, and 1.0% and 1.6% fat, respectively [26]. In decreasing quantities, soluble sugars included verbascose, stachyose, sucrose, ciceritol, and raffinose. Brand et al. [27] reported a mineral composition in g/kg 0.9 Ca, 5.9 P, and 1.1 Mg, and in mg/kg 4.82 Cu, 41.9 Zn, 20.4 Mn, and 79.5 Fe, an amino acid concentration in g/kg DM 17.5 Lysine and 1.3 Methionine, and 160 g/kg acid detergent fiber (ADF) and 1.78 g/kg neutral detergent fiber (NDF). Furthermore, Kökten et al. [28] analyzed the fatty acid composition of Turkish *Vicia* species; the unsaturated fatty acid content of 80% was similar to other *Vicia* species, but with 30% 18:1 Δ 9, it was richer in oleic acid.

However, the presence of the antinutritional sulfur-containing dipeptide γ -glutamyl-S-ethenyl-cysteine (GEC) limits the use of Narbon vetch in animal nutrition. GEC concentration depends on surface soil sulfur concentration of the growing environment; however, in some varieties, such as genotype SA 22654, GEC and seed sulfur concentration are uncorrelated [29]. Depending on the variety, GEC may vary between 0.4% and 3.77% [30]. In the study of Gómez-Izquierdo [31], variety ZV-220 contained 1.52% GEC. Varieties ZU-154 and Icarda-2470 in the study of Martín-Pedrosa et al. [26] contained 1.6% and 1.7% GEC, respectively; other ANFs included inositol phosphates and trypsin (6.95% and 7.01%, respectively), and chymotrypsin inhibitor units (2.19% and 2.63%, respectively), but Narbon vetch lacks lectins, canavanine, and convicine. Programs were established to develop new, high producing varieties destined for animal feeds, with reduced amounts of ANFs, increased amounts of bioactive factors, and increased tolerance and resistance to pests [20]. New varieties are registered for their use in animal nutrition. For example, in 2015, the Castile–Leon Agriculture Technology Institute (ITACyL) registered the Narbon vetch variety “Gario” (registration nr 20155218; [32]), and registration of variety “Oberón” is currently underway.

In Spain, there is interest from the animal feed industry to substitute soybean meal with Narbon vetch. The agricultural cooperatives AGROPAL and NUTECAL are investigating the agronomic and economic characteristics of Narbon vetch with a special focus on the development of an optimal feed for dairy sheep [33,34]. Narbon vetch was described by Mateo-Box [35] as having excellent quality and being much appreciated as fodder for all types of cattle. In pig feeds, however, Narbon vetch was described as being unpalatable, with a garlic-like flavor due to the presence of GEC [24,36]. According to Francis et al. [25], because of the increasing value of vetches for animal feed, the several vetch species, including Narbon vetch, require far more breeding and research support than what is currently directed toward them. Indeed, only very few studies are available that evaluate Narbon vetch inclusion in pig feeds.

4.2. Influence of Narbon Vetch on Production Traits

The results of the present study indicate that pigs initially showed aversion to the novel feed, thus resulting in reduced DFI both at the start of the growing period and after the switch from the growing to the fattening–finishing period. This aversive response was higher at an increased percentage of inclusion of Narbon vetch in the diet and was most pronounced for inclusion at 10% and 20%; DFI in pigs feeding on 5% Narbon vetch was mostly not significantly different from the V0 control group. The reduction in DFI resulted in reduced DBWG, in particular in V20. The results indicate that pigs resumed DFI and DBWG after a period of adaptation to the novel feed that lasted a few weeks. Indeed, MFI was similar in all four treatments. The chemical analysis of feed samples (Table 1; Table 2) shows slight variations in the protein content, and in particular a slight overformulation of crude protein content in V20. However, when protein content in the diet is sufficient, pigs eat to satisfy their energy requirements as long as this is the first limiting resource

[37]. In addition, pigs are more likely to respond to the content of the first limiting amino acid in the diet rather than to the dietary protein content per se. The first limiting amino acid in typical swine diets is lysine [38]; the amount of lysine was slightly lower in diet V5 than in the other diets. Since DFI in pigs in V5 was similar to those in V0, and since MFI was similar in all four treatments after a period of adaptation, our results suggest that slight differences in protein or in lysine content were trivial.

Our results support observations by Enneking [39], who investigated in young Large White pigs of approximately 20 kg the effect on DFI of 12.5% and 25% inclusion of Narbon vetch. Pigs were fed consecutively a regular diet for four days, a treatment diet for four days, and a regular diet for four days. DFI was reduced upon first exposure and during the treatment period, but this was not significant at 12.5% [39]. Because of the short duration of the treatment period, it was not possible in their study to observe adaptation to the novel diet. Gómez-Izquierdo et al. [15,40] investigated the inclusion of 0%, 5%, 15%, and 25% Narbon vetch that contained 1.52% GEC in diets fed to Duroc × (Large White × Landrace) barrows between 40 to 171 days of age, corresponding to a BW between 11 and 114 kg. Overall, in the first period up to 61 days of age and approximately 22 kg body weight, they observed that 5% inclusion resulted in a significant *increase* in DFI and DBWG, whereas 15% gave results similar to the control diet; 25% inclusion resulted in significantly reduced DFI and DBWG [15]. Between 61 and 171 days of age, Gómez-Izquierdo et al. [40] observed that, again, 5% inclusion resulted in an *increased* DFI and DBWG, but this was no longer significant. Inclusion of 15% Narbon vetch resulted in a reduced DFI (but this was not significant with respect to the control diet) and a significantly reduced DBWG; inclusion of 25% further significantly reduced DFI and DBWG with respect to 15% inclusion [40]. In these studies, trends over time were not investigated and the presence of an adaptation period was not established. In the study of Enneking [39], feed efficiency was not investigated. Gómez-Izquierdo et al. [15,40] observed that, overall, FCE was significantly lower at 15% and 25% inclusion between 40 to 61 d of age and between 61 and 171 d of age. Results of the present study show that, with exceptions during the first introduction with the novel feed, feed efficiency is sustained on all levels of Narbon vetch inclusion. This indicates that a negative response in DBWG in the treatments with a larger percentage of inclusion is mostly proportional to the response in DFI. However, Figure 1 shows the accumulative result of (small) differences in feed efficiency between the four diets, i.e., the amount of BW that is eventually achieved on a cumulative amount of FI; at a similar cumulative FI, pigs in V0 reach the highest BW and pigs in V20 reach the lowest BW, whereas BWs in pigs in V5 and V10 are very similar up to about an intake of approximately 255 kg and a BW of 125 kg; pigs in V10 and V20 are estimated to reach a lower mature body weight. Therefore, the economic implications of substituting commercial diets with Narbon vetch depend on the extra total amount of feed that may be required and associated feed costs, and on the fixed cost of additional days on-farm that are required to reach a given slaughter weight. Profeta and Hamm [10] showed that German consumers are willing to pay a premium price for animal products produced with local feeds, which may account for the higher production costs of such products when they are sold as a differentiated product in local supply chains. Eventually, consumer's perception of eating quality will determine the possibility to develop a new, differentiated product based on novel feed ingredients [41].

Because our study shows that pigs appear to adapt to the taste of Narbon vetch, even at 20% inclusion, the negative implications of Narbon vetch inclusion may be reduced if the transition to the novel feed would have been milder, for example, through adopting a longer transition period. In the present study, according to current common practice, Narbon beans were not pretreated to remove ANFs before inclusion in the diet formulations. According to The European Innovation Partnership for Agricultural productivity and Sustainability (EIP-AGRI) [9], biorefinery of pulses can have considerable advantages in that it can increase the protein content and reduce ANFs. Enneking [39] observed that the feed-inhibitory activity of Narbon vetch sustained autoclaving for 1 h at 121 °C, suggesting that GEC is heat stable; however, ANFs were extracted in aqueous 30% ethanol. They furthermore established that ANFs were only present in the cotyledons and embryo fraction of the seeds, and not in the seed coats [39]. In addition, in our experiment, DBWG in V20 in period 1 varied

between -114 to $+1179$ g/d (results not presented). Variation in DBWG between pigs can be exploited to select for pigs that are better able to transform local feed ingredients into meat [5,14].

5. Synthesis

Because of a dependency of the EU on soybean meal imports as an animal feed ingredient, there is an interest in investigating the competitiveness of locally produced protein crop alternatives. Local production of animal feed crops is often considered more sustainable than dependency on imported feedstuffs when this results in, e.g., a reduced amount of energy used in their transport, in on-farm crop rotation reducing the risk of crop diseases, and in improving the economic viability of local farms. However, the economic sustainability of using local feed crops is lowered when suboptimal nutritional quality of the crop results in reduced animal production efficiency, thus reducing farm profitability. Narbon vetch is of interest as a potential protein crop alternative because it is resistant to unfavorable climatic and soil conditions, resistant to common pests, has a favorable nutritional profile, and is well adapted to the Mediterranean climate; however, the presence of the antinutritional factor γ -glutamyl-S-ethenyl-cysteine limits its use in animal nutrition. Results of the present study show a clear depression in daily feed intake and as a consequence, a lower daily body weight gain up to four weeks after introduction of the novel feed. However, pigs adapted to the novel feed, and daily feed efficiency, i.e., body weight gained per unit feed intake, was only significantly reduced at the beginning of the feed transition period at the highest inclusion level of 20% Narbon vetch. The initial depression in feed intake may be reduced with a slower transition period to the novel feed and by genetic improvement of Narbon vetch varieties to lower its GEC content. Furthermore, genetic selection may improve crop yields and nutrient content. Although daily feed efficiency was mostly unaffected by inclusion of Narbon vetch in the diet, economical sustainability of substituting soybean meal with Narbon vetch will depend its cost relative to that of soybean meal and on the fixed costs of additional days on-farm required for pigs to reach slaughter weight. Finally, the selling price of pork from pigs fed with Narbon vetch may increase when it can be sold under a different label. Future research will investigate the meat quality of pork from pigs fed with Narbon vetch.

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References

1. Wang, J.; Lui, Q.; Hou, Y.; Qin, W.; Lesschen, J.P.; Zhang, F.; Oenema, O. International trade of animal feed: Its relationships with livestock density and N and P balances at country level. *Nutr. Cycl. Agroecosys.* **2018**, *110*, 197–211, doi:10.1007/s10705-017-9885-3.
2. Dei, H.K. Soybean as a feed ingredient for livestock and poultry. *IntechOpen* **2011**, doi:10.5772/17601.
3. Boerema, A.; Peeters, A.; Swolfs, S.; Vandevenne, F.; Jacobs, S.; Staes, J.; Meire, P. Soybean trade: Balancing environmental and socio-economic impacts of an intercontinental market. *PLoS ONE* **2016**, *11*, e0155222, doi:10.1371/journal.pone.0155222.

4. Roman, G.V.; Epure, L.I.; Toader, M.; Lombardi, A.R. Grain legumes—Main source of vegetable proteins for European consumption. *Agro. Life Sci. J.* **2016**, *5*, 178–183.
5. Rauw, W.M.; Rydhmer, L.; Kyriazakis, I.; Øverland, M.; Gilbert, H.; Dekkers, J.C.M.; Hermes, S.; Bouquet, A.; Gómez Izquierdo, E.; Louveau, I.; et al. Prospects of sustainability of pig production in relation to climate change and novel feed resources. *J. Sci. Food Agric.* **2020**, doi:10.1002/jsfa.10338.
6. Van Krimpen, M.M.; Bikker, P.; Van der Meer, I.M.; Van der Peet-Schwering, C.M.C.; Vereijken, J.M. *Cultivation, Processing and Nutritional Aspects for Pigs and Poultry of European Protein Sources as Alternatives for Imported Soybean Products*; Report 662; Wageningen UR Livestock Research: Lelystad, The Netherlands, 2013.
7. European Parliament. The EU deficit: What Solution for a Long-Standing Problem? Report 2010/2011(INI), 2001. Available online: <http://www.europarl.europa.eu/sides/getDoc.do?type=REPORT&reference=A7-2011-0026&language=EN> (accessed on 6 February 2020).
8. Peters, C.J.; Bills, N.L.; Wilkins, J.L.; Fick, G.W. Foodshed analysis and its relevance to sustainability. *Renew. Agr. Food Syst.* **2009**, *24*, 1–7, doi:10.1017/S1742170508002433.
9. Leinonen, I.; Kyriazakis, I. How can we improve environmental sustainability of poultry production? *Proc. Nutr. Soc.* **2016**, *75*, 265–273, doi:10.1017/S0029665116000094.
10. Profeta, A.; Hamm, U. Who cares about local feed in local food products? Results from a consumer survey in Germany. *Br. Food J.* **2019**, *121*, 711–724, doi:10.1108/BJFJ-07-2018-0446.
11. EIP-AGRI. Final Report, EIP-AGRI Focus Group Protein Crops. 2014. Available online: https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/fg2_protein_crops_final_report_2014_en.pdf (accessed on 6 February 2020).
12. De Visser, C.L.M.; Schreuder, R.; Stoddard, F. The EU's dependency on soya bean import for the animal feed industry and potential for EU produced alternatives. *OCL* **2014**, *21*, D407, doi:10.1051/ocl/2014021.
13. Galioto, F.; Paffarini, C.; Chiorri, M.; Torquati, B.; Cecchini, L. Economic, environmental, and animal welfare performance on livestock farms: Conceptual model and application to some case studies in Italy. *Sustainability* **2017**, *9*, 1615, doi:10.3390/su9091615.
14. ERANET SusPig. Project description. Available online: <http://suspig-era.net/> (accessed on 6 February 2020).
15. Gómez-Izquierdo, E.; de Mercado, E.; Gómez-Fernández, J.; Tomás, C.; Guillamón, E.; Varela, E.; Muzquiz, M.; Pedrosa, M.M.; López-Nuez, P.; Latorre, M.A. Tolerancia a diferentes factores antinutritivos en lechones alimentados con guisantes de invierno (*Pisum sativum*) y alberjón (*Vicia narbonensis*) en la fase estárter. *ITEA* **2018**, *114*, 243–258, doi:10.12706/itea.2018.015.
16. Parks, J.R. *A Theory of Feeding and Growth of Animals*; Springer: Berlin/Heidelberg, Germany, 1982.
17. Archer, J.A.; Pitchford, W.S. Phenotypic variation in residual food intake of mice at different ages and its relationship with efficiency of growth, maintenance and body composition. *Anim. Sci.* **1996**, *63*, 149–157, doi:10.1017/S1357729800028381.
18. Koch, R.M.; Swiger, L.A.; Chambers, D.; Gregory, K.E. Efficiency of feed use in beef cattle. *J. Anim. Sci.* **1963**, *22*, 486–494, doi:10.2527/jas1963.222486x.
19. Rauw, W.M.; de Mercado de la Peña, E.; Gomez-Raya, L.; García Cortés, L.A.; Ciruelos, J.J.; Gómez Izquierdo, E. Impact of environmental temperature on production traits in pigs. *Sci. Rep.* **2020**, *10*, 2106, doi:10.1038/s41598-020-58981-w.
20. Nadal Moyano, S.; Martínez Araque, C.; Perea Torres, F.; Saavedra Saavedra, M.M.; Córdoba Jiménez, E.M. *Guías de Cultivos. Serie Leguminosas: Los Alberjones*; Junta de Andalucía, Instituto de Investigación y Formación Agraria y Pesquera, Consejería de Agricultura y Pesca: Sevilla, Spain, 2012.
21. Nadal, S.; Moreno, M.T. Behaviour of Narbon bean (*Vicia narbonensis* L.) under presence-absence of broomrape (*Orobancha crenata* Forsk.) in rainfed agricultural systems in Southern Spain. *J. Sust. Agr.* **2007**, *30*, 133–143, doi:10.1300/J064v30n04_10.
22. Casquero, P.A.; Oláiz, I.; Marcos, M.F.; Campelo, P.; Reinoso, B. Leguminosas grano tradicionales cultivadas en España. *Vida Rural*, December, 2009; 42–46. Available online: https://www.miteco.gob.es/ministerio/pags/biblioteca/Revistas/pdf_Vrural/Vrural_2009_300_42_46.pdf (accessed on 6 February 2020).
23. Haffani, S.; Mezni, M.; Chaïbi, W. Agronomic performances of three vetch species growing under different drought levels. *Chil. J. Agr. Res.* **2014**, *74*, 263–272, doi:10.4067/S0718-58392014000300003.
24. Enneking, D.; Maxted, N. Narbon bean. *Vicia narbonensis* L. (Leguminosae). In *Evolution of Crop Plants*; Smartt, J., Simmonds, N.W., Eds.; Longman: London, UK, 1995; pp. 316–321.

25. Francis, C.M.; Enneking, D.; Abd El Moneim, A. When and where will vetches have an impact as grain legumes? In *Linking Research and Marketing Opportunities for Pulses in the 21st Century*; Current Plant Science and Biotechnology in Agriculture; Knight, R., Ed.; Springer: Dordrecht, The Netherlands, 1999; Volume 34, pp. 375–384.
26. Martín-Pedrosa, M.; Varela, A.; Guillamon, E.; Cabellos, B.; Burbano, C.; Gomez-Fernandez, J.; de Mercado, E.; Gomez-Izquierdo, E.; Cuadrado, C.; Muzquiz, M. Biochemical characterization of legume seeds as ingredients in animal feed. *Span. J. Agric. Res.* **2016**, *14*, e0901, doi:10.5424/sjar/2016141-7450.
27. Brand, T.S.; Brandt, D.A.; Cruywagen, C.W. Chemical composition, true metabolisable energy content and amino acid availability of grain legumes for poultry. *S. Afr. J. Anim. Sci.* **2004**, *34*, 116–122, doi:10.4314/sajas.v34i2.3815.
28. Kökten, K.; Koçak, A.; Bağci, E.; Akçura, M.; Çelik, S. Tannin, protein contents and fatty acid composition of the seeds of several *Vicia L.* species from Turkey. *Grasas Aceites* **2010**, *61*, 404–408, doi:10.3989/gya.021310.
29. Berger, J.D.; Siddique, K.H.M.; Loss, S.P. Cool season grain legumes for Mediterranean environments: The effect of environment on non-protein amino acids in *Vicia* and *Lathyrus* species. *Aust. J. Agr. Res.* **1999**, *50*, 403–4012, doi:10.1071/A98097.
30. Castleman, G.H. *A Guide for Feeding Narbon Beans to Animals*; Department of Natural Resources and Environment, Victorian Institute for Dryland Agriculture: Walpeup, Victoria, Australia, 2000; p. 4.
31. Gómez-Izquierdo, E. Efecto Sobre el Rendimiento Productivo y Calidad de la Canal de la Inclusión de Guisantes (*Pisum sativum*) y Alberjón (*Vicia narbonensis*) en el Pienso de Lechones y Cerdos de Cebo. Ph.D. Thesis, Universidad Politécnica de Madrid, Madrid, Spain, 2015. Available online: http://oa.upm.es/39060/1/EMILIO_GOMEZ_IZQUIERDO.pdf (accessed on 6 February 2020).
32. BRVP. Boletín del Registro de Variedades Protegidas. Gobierno de España, Ministerio de Agricultura, Alimentación, y Medio Ambiente. Boletín Nr 5/2015. 2015. Available online: https://www.mapa.gob.es/ministerio/pags/Biblioteca/Revistas/pdf_RVP%2FRVP_2015_5.pdf (accessed on 6 February 2020).
33. AGROPAL, 2015. Nuevos Proyectos Para Garantizar tu Futuro. No 136. Available online: <http://www.agropalsc.com/extras/Documentos/136Abril2015WEB.pdf>. pp. 26–27 (accessed on 6 February 2020).
34. AGROPAL, 2017. Nuevos Proyectos Para Garantizar tu Futuro. No 143. Available online: <http://www.agropalsc.com/extras/Documentos/143W.pdf>. pp. 23–25 (accessed on 6 February 2020).
35. Mateo-Box, J.M. *Leguminosas de Grano*; Salvat Editores: Barcelona, Spain, 1961; pp.145–151.
36. Arias, M.; Simó, C.; Ortiz, L.T.; de los Mozos Pascual, M.; Barbas, C.; Cifuentes, A. Detection and quantitation of a bioactive compound in *Vicia narbonensis L.* seeds by capillary electrophoresis-mass spectrometry: A comparative study with UV detection. *Electrophoresis* **2005**, *26*, 2351–2359, doi:10.1002/elps.200410224.
37. Kyriazakis, I.; Emmans, G.C. The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. *Br. J. Nutr.* **1995**, *73*, 19–207, doi:10.1079/BJN19950023.
38. Liao, S.; Wang, T.; Regmi, N. Lysine nutrition in swine and the related monogastric animals: Muscle protein biosynthesis and beyond. *Springerplus* **2015**, *4*, Article 147, doi:10.1186/s40064-015-0927-5.
39. Enneking, D. Isolation and identification of γ -glutamyl-S-ethenyl cysteine as antifeedant component from the seeds of *Vicia narbonensis L.* Chapter 6. Ph.D. Thesis, University of Adelaide, Adelaide, Australia, 1994. Available online: <https://digital.library.adelaide.edu.au/dspace/bitstream/2440/37799/10/02whole.pdf> (accessed on 6 February 2020).
40. Gómez-Izquierdo, E.; Ciruelos, J.J.; Tomás, C.; Guillamón, E.; Varela, E.; Martín-Pedrosa, M.; López-Nuez, P.; Latorre, M.A.; de Mercado, E. Interés del alberjón (*Vicia narbonensis*) en alimentación de cerdo graso. In *Datos Productivos*. AIDA, XVIII Jornadas sobre Producción Animal: Zaragoza, España, 2019; pp. 269–271.
41. Grunert, K.G.; Bredahl, L.; Brunsø, K. Consumer perception of meat quality and implications for product development in the meat sector—A review. *Meat Sci.* **2004**, *66*, 259–272, doi:10.1016/S0309-1740(03)00130-X.

