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Effect of Italian heavy pig diets based on different barley varieties with or without non-starch polysaccharides degrading enzymes on growth performance, carcass characteristics and fresh thigh quality

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ABSTRACT
The effect of diets based on two different barley varieties, with or without non-starch polysaccharides (NSP) degrading enzymes was evaluated on growth performance, carcass characteristics and fresh thigh quality in Italian heavy growing-finishing pigs. Pigs (64) were assigned to four diets: two diets based on 85% of hulled normal-amylose barley (Cometa, with or without NSP enzyme complex) and two diets based on 85% of hulless low-amylose barley (Alamo, with or without NSP enzyme complex). The diets were formulated according to three growth phases with same lisyne:digestible energy ratio. The NSP enzyme complex did not improve the Cometa and Alamo diets in terms of pig growth performance, carcass characteristics and fresh thigh quality. Throughout the study, the Alamo group had greater ($p < 0.05$) final body weight, average daily gain and gain per megacalorie of digestible energy than the Cometa group. Higher ($p < 0.05$) carcass and thigh weights, and lower ($p < 0.01$) thigh chilling losses were observed for the Alamo group compared with the Cometa group. The Cometa diet decreased ($p < 0.01$) polyunsaturated fatty acids level, and increased ($p < 0.01$) monounsaturated fatty acid content and saturated fatty acids/polyunsaturated fatty acids ratio in subcutaneous fat of fresh thighs. No appreciable differences were observed in the color of subcutaneous fat and *biceps femoris* of pigs fed the Cometa and Alamo diets. Feeding hulless low-amylose barley to growing-finishing pigs can be valuable to promote growth performance and carcass characteristics. No NSP enzyme complex is needed when hulled normal-amylose barley or hulless low-amylose barley are used in diets for heavy pigs.

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Introduction

In Italy, the pig industry is mainly aimed to the breeding of heavy pig, from 150 to 170 kg body weight (BW), for cured meat production with Protected Designation of Origin (PDO), especially Parma and San Daniele hams (Bosi & Russo 2004). Because corn is rich in linoleic acid (C 18:2*n-6*) and carotenoid pigments, the Consortia of Parma and San Daniele hams set to 55% on a dry matter (DM) basis the maximum level of corn inclusion in pig diets (Consorzio del Prosciutto di Parma 2015; Consorzio del Prosciutto di San Daniele 2015). Barley having a low concentration of linoleic acid and carotenoids (Kim et al. 2014), can be a valid alternative to corn in the diets of heavy pigs for the production of PDO Italian meat products (Prandini, Sigolo, Gallo, et al. 2015; Prandini, Sigolo, Giuberti, et al. 2015). Nevertheless, the Consortia of Parma and San Daniele hams establish a maximum limit of 40% (on DM basis) for the use of barley in pigs' diet (Consorzio del Prosciutto di Parma 2015; Consorzio del Prosciutto di San Daniele 2015). Barley is rich in dietary fibre mainly arabinoxylans and β-glucans which are classified as non-starch polysaccharides (NSP) (Holtekjølen et al. 2006; Knutsen & Holtekjølen 2007). Increased dietary fibre level was associated with reduced available energy content of feed (Noblet & Le Goffe 2001). The addition of NSP-degrading enzymes to feeds was reported as a strategy to improve fibre utilisation, and thereby nutrient digestion in pig (Kerr & Shurson 2013). However, considerable variation exits

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in the fibre and starch contents as well as in starch type of barley grain leading to large variation in terms of digestible energy content (Bowman et al. 2001; Jha et al. 2010; Biel & Yacyno 2013).

The aim of the study was to evaluate the effect of diets based on hulled normal-amylose or hulless low-amylose barley varieties, with or without the addition of a NSP enzyme complex, on growth performance, carcass characteristics, and fresh thigh quality in Italian heavy growing-finishing pigs.

Materials and methods

Animals and housing

The study was conducted at the CREA – Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (San Cesario sul Panaro, MO, Italy), and animal care and use practices during this study conformed to the directive of the European Parliament and the Council of the European Union (2010) on the protection of animals used for scientific purposes.

The study was performed using 64 pigs (Italian Large White × Italian Duroc) with initial BW of 48 ± 3 kg (122 days old). The pigs were allocated to pens based on BW and sex. Each pen contained four pigs (2.25 m^2 per pig) of the same sex, and pens were randomly assigned to four experimental diets (two pens of castrated males and two pens of females per treatment). The lighting was natural throughout the study.

Dietary treatments

Four experimental diets were formulated: (1) diet with 85% of a hulled normal-amylose barley variety named Cometa (Cometa); (2) diet with 85% of a hulless low-amylose barley variety named Alamo (Alamo); (3) Cometa diet supplemented with a NSP enzyme complex (1 g/kg feed) and (4) Alamo diet supplemented with a NSP enzyme complex (1 g/kg feed). The two barley varieties were grown in the same pedo-climatic conditions (CREA – Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, San Cesario sul Panaro, MO, Italy). The NSP enzyme complex (E 1602) was derived from *Tricoderma longibrachiatum* and contained endo-1,4-β-glucanase (EC 3.2.1.4), endo-1,3(4)-β-glucanase (EC 3.2.1.6) and endo-1,4-β-xylanase (EC 3.2.1.8).

For every treatment, the diets were formulated according to three growth periods (P1, from 40 to 80 kg BW; P2, from 80 to 120 kg BW and P3, from 120 to 170 kg BW), with the same lysine:digestible energy (DE) ratio within the period (2.60, 2.20 and 1.90, respectively, in P1, P2 and P3) according to NRC (1998) requirements for P1 and P2, and according to the requirements for high-performing pigs (Manini et al. 1997) for P3. The pigs had free access to water, and the diets were offered twice a day in a liquid form (with a water to feed ratio of 2.5:1) at an average of 8.7% of pig metabolic weight ($BW^{0.75}$) up to 120 kg BW. After 120 kg BW supplied feed was kept constant until the end of the study (147 days). To ensure the same DE daily intake among treated groups, differences in supplied amount (in weight) were considered and were +8% for Cometa compared with Alamo groups. The feed offered was adjusted weekly on the basis of an hypothetical gain verified by previous similar experiences in the CREA – Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (San Cesario sul Panaro, MO, Italy).

Growth performance

The pigs (122 days old) were individually weighed at the beginning, after 56 days, and at the end of the study (147 days). The average daily intake (ADG), gain: feed ratio (G:F) and gain per megacalorie of DE (G/Mcal DE) were calculated for every replicate within treatment and for the periods of days 0–56, days 57–147 and days 0–147.

Carcass measurements

At slaughter, the pigs (169 ± 3 kg average final BW) were electrically stunned and the cold carcasses were weighed to calculate the dressing percentage. The back fat and loin depth were measured by Fat-O-meat'er (Carometec, A/S, Herlev, Denmark) in accordance with European Commission (2014) authorizing methods for grading pig carcasses in Italy. Thus, lean percentage was estimated using these two parameters (European Commission 2014). For each carcass, the hot thighs of both sides, including shank, knuckle and muscles [4018 leg short cut; United Nations Economic Commission for Europe (UNECE) 2006] were weighed. The thigh yield and chilling losses (after 24 h of chilling) were also determined. The pH was measured after 45 min and 24 h *post mortem* on the semimembranosus and *biceps femoris* muscles of the thigh.

Fresh thigh quality

The color was measured on the *biceps femoris* muscle and subcutaneous fat of all the left thighs using a Konica Minolta Chroma Meter CR-300 (Konica Minolta

Sensing, Inc., Osaka, Japan) and operating with a K6770 illuminant. The CIE Lab L* (lightness), a* (redness) and b* (yellowness) color space was used to determine the color. Then the Chroma $[C^* = (a^{*2} + b^{*2})^{1/2}]$ and the Hue angle $\{H^* = [\tan^{-1}(b^*/a^*)]\}$ were obtained. The C* describes the color saturation whereas H* the tint. The subcutaneous fat of all left thighs was also analyzed for iodine value using the Hanus method 920.158 (AOAC 1990) and for fatty acid composition by gas chromatography as described below.

Chemical analyses

Dried barley grains and diets collected in each growth period were ground through a 1-mm screen using a Retsch-type ZM100 centrifugal grinding mill (Retsch, Haan, Germany). The samples were analyzed according to AOAC (2012) for moisture (method 945.15), crude protein (method 984.13), crude fibre (method 962.09) and ether extract (method 920.29). The total starch was determined according to Masoero et al. (2010). Amino acids were determined by using a Carlo Erba model 3A29 amino acid analyzer (Carlo Erba Strumentazione, Corsico, Italy; Moore 1963; Eggum 1968; Moore et al. 1980).

Barley grains

Barley grains were also analyzed for fibre fractions (neutral detergent fibre, acid detergent fibre and acid detergent lignin; Van Soest et al. 1991) and β-glucan (Megazyme mixed-linkage β-glucan assay kit; K-BGLU 07/11, Megazyme Int., Wicklow, Ireland) and amylose (Megazyme amylose/amylopectin assay kit; K-AMYL 07/11, Megazyme Int.) contents. The DE of the two barley varieties was calculated using Perez et al.'s (1980) equation. The energy and nutrient composition of the two barley varieties are shown in Table 1.

Diets

The DE of the diets was calculated from the DE of single raw materials reported by Sauvant et al. (2002), except for barley (Perez et al. 1980). The net energy (NE) was calculated using Sauvant et al.'s (2002) Equation 4. The calcium and phosphorous contents of the diets were determined by inductively coupled plasma atomic emission spectrometry [U.S. Environmental Protection Agency (EPA) 2000] after microwave-assisted acid digestion (method 3052; EPA 1996). Digestible phosphorous and lysine were calculated according to Sauvant et al. (2002). The diets were characterised for their resistant starch (RS) content

Table 1. Energy and nutrient composition of hulled normal-amylose barley (Cometa) and hulless low-amylose barley (Alamo).

Item	Cometa	Alamo
Analyzed chemical composition, % as fed		
DM	88.31	89.01
CP	10.80	14.84
Ether extract	1.75	2.20
Crude fibre	4.20	1.56
NDF	15.32	7.78
ADF	5.05	1.63
ADL	0.97	0.57
Total starch	50.05	55.67
Amylose, % dry starch	29.4	7.8
β-glucans	4.23	6.48
Lysine	0.39	0.48
Methionine + cystine	0.44	0.61
Threonine	0.38	0.51
Leucine	0.73	0.99
Isoleucine	0.38	0.54
Valine	0.56	0.75
Histidine	0.25	0.35
Arginine	0.53	0.69
Phenylalanine + tyrosine	0.80	1.15
DE, calculated energy, kcal/kg	2970	3280

DM: dry matter; CP: crude protein; NDF: neutral detergent fibre; ADF: acid detergent fibre; ADL: acid detergent lignin; DE: digestible energy calculated using Perez et al.'s (1980) equation.

(Englyst et al. 1996). A predicted glycemic index (pGI) was calculated for each diet after *in vitro* starch digestion over time performed with an enzymatic method and using milled white bread (1 mm screen; 72.3% of starch on a DM basis) as reference sample for the hydrolysis index calculation (Giuberti, Gallo, Cerioli, et al. 2012; Giuberti, Gallo, & Masoero 2012). The linoleic acid content of each diet and the fatty acid composition of the subcutaneous fat were determined using a Trace Ultra gas chromatograph equipped with a S 2000 automatic sampler, a flame ionisation detector (Thermo Fisher Scientific Inc., MI, Italy) and a SP-2380 capillary column (30 m × 0.25 mm i.d.; 0.20 μm film thickness; Supelco, Inc., Bellefonte, PA) after lipid extraction with a modified Folch's technique (Christie 1989; Prandini et al. 2007) and lipid transesterification with methanolic HCl (Stoffel et al. 1959). Ingredients, energy, nutrient composition and *in vitro* starch characterisation of the diets used in P1, P2 and P3 are reported in Table 2.

Statistical analysis

Data were tested for normality with the Shapiro–Wilk test before statistical analysis. Then, data were analyzed using the GLM procedure of SAS® (SAS Inst. Inc., Cary, NC) according to a 2^3 factorial arrangement in a completely randomised design according to the following model: $Yijkl = \mu + Ai + Bj + Sk + \varepsilon ijkl$, in which Yijkl is the *l*th observation in the *i*th barley variety ($l = 2$;

Table 2. Ingredients, energy, nutrient composition and *in vitro* starch characterisation of diets for heavy growing-finishing pigs in the three growth periods (P1, P2 and P3).

	P1, from 40 to 80 kg		P2, from 80 to 120 kg		P3, from 120 to 170 kg	
Item	Cometa	Alamo	Cometa	Alamo	Cometa	Alamo
Ingredients, %						
Corn	4.64	11.25	8.63	11.62	11.74	11.76
Barley	85.00	85.00	85.00	85.00	85.00	85.00
Soybean meal, 48% CP	7.00	–	3.00	–	–	–
L-lysine HCL	0.30	0.53	0.29	0.38	0.26	0.24
DL-methionine	0.03	0.03	0.02	–	–	–
L-threonine	0.03	0.07	0.01	–	–	–
L-tryptophan	–	0.02	–	–	–	–
Premix[a]	3.00	3.10	3.05	3.00	3.00	3.00
Analyzed chemical composition, % as fed						
DM	88.32	89.21	88.62	89.17	89.14	89.67
CP	13.16	14.10	11.57	13.90	10.36	13.78
Crude fibre	4.54	2.95	4.39	2.96	4.28	2.96
Ether extract	1.56	2.25	1.78	2.41	1.78	2.30
Linoleic acid (C 18:2*n-6*)	1.65	1.73	1.70	1.74	1.74	1.74
Total starch	47.89	54.16	49.30	55.09	50.88	55.36
RS (% starch)	15.91	7.82	16.88	7.47	16.02	7.23
Calcium	0.77	0.77	0.77	0.75	0.75	0.75
Phosphorous	0.50	0.49	0.49	0.47	0.47	0.47
Lysine	0.79	0.85	0.67	0.73	0.57	0.62
Methionine + cystine	0.24	0.26	0.21	0.23	0.17	0.23
Threonine	0.50	0.54	0.42	0.47	0.36	0.47
Tryptophan	0.16	0.17	0.13	0.15	0.12	0.15
Calculated parameters						
pGI	68	79	65	78	64	78
Digestible phosphorous[b], % as fed	0.23	0.23	0.23	0.22	0.22	0.22
Digestible lysine[b], % as fed	0.65	0.75	0.56	0.63	0.48	0.52
DE, kcal/kg	2950	3202	2946	3202	2946	3209
NE, kcal/kg	2130	2350	2158	2353	2181	2360
Lysine:DE[c]	2.67	2.66	2.28	2.29	1.92	1.94

Cometa: diet with 85% of hulled normal-amylose barley variety (Cometa); Alamo: diet with 85% of hulless low-amylose barley variety (Alamo); CP: crude protein; DM: dry matter; RS: resistant starch; pGI: predicted glycemic index calculated with the equation proposed by Giuberti, Gallo, Cerioli, et al. (2012) using white bread as a reference; DE: digestible energy calculated from the DE of single raw materials reported by Sauvant et al. (2002) except for barley (Perez et al. 1980); NE: net energy calculated using Sauvant et al.'s (2002) Equation 4.

[a]Provided vitamins and minerals per kilogram of feed (Istituto delle Vitamine SpA, Segrate, Italy): vitamin A, 15,000 U; vitamin D3, 2000 U; vitamin E, 50 mg; vitamin K3, 2.5 mg; vitamin B1, 2 mg; vitamin B2, 5 mg; vitamin B6, 4 mg; vitamin B12, 0.03 mg; biotin, 0.15 mg; niacin, 25 mg; D-pantothenic acid, 15 mg; choline chloride, 350 mg; Mn, 25 mg as manganous oxide; Fe, 150 mg as ferrous sulfate; Cu, 15 mg as copper sulfate; Zn, 100 mg as zinc oxide; I, 1.5 mg as calcium iodide; Co, 0.20 mg as basic cobaltous carbonate monohydrate and Se, 0.1 mg as sodium selenite.

[b]Calculated according to Sauvant et al. (2002).

[c]Calculated as ratio between lysine (g/kg) and digestible energy (Mcal/kg).

Cometa, Alamo), the *j*th enzyme treatment ($j = 2$; enzyme, no enzyme) and the *k*th sex ($k = 2$; gilt, barrow), μ is the overall mean and $\varepsilon ijkl$ is the residual error. Fixed effects were barley, enzyme, sex and their interactions. First and second order interactions were not significant and therefore removed from the model. Pen was the experimental unit. The initial weight as covariate was not significant and therefore not considered in the model. Differences with a p value of <0.05 were considered to be statistically significant.

Results

Growth performance

Growth performance is shown in Table 3. There were no barley × enzyme, barley × sex and barley × enzyme × sex interactions nor an enzyme effect on pig growth performance. A sex effect was observed on ADG ($p = 0.018$), G:F ($p = 0.022$) and G/Mcal DE ($p = 0.020$) in the days 0–55 period. In this period females grew faster than castrated males independently of the barley type and presence of enzyme, and greater G:F and G/Mcal DE were observed. A barley effect was found on final BW ($p = 0.019$), and ADG and G/Mcal DE in the days 56–147 period ($p < 0.05$) and throughout the study (days 0–147; $p < 0.05$). In particular, the pigs fed the Alamo diet had greater final BW, ADG and G/Mcal DE than the pigs fed the Cometa diet.

Carcass characteristics

Carcass characteristics are shown in Table 4. There were no barley × enzyme, barley × sex and barley × enzyme × sex interactions nor an enzyme or sex effect on carcass characteristics. The pigs fed the Alamo diet had increased carcass ($p < 0.01$) and thigh

Table 3. Growth performance of pigs fed diets based on two different barley varieties with or without non-starch polysaccharides degrading enzymes.

	Barley		Sex			*p* value		
Item	Cometa	Alamo	Female	Castrated male	SEM	Enzyme	Barley	Sex
BW, kg								
Initial	48	48	48	48	1	0.970	0.996	0.731
56 days	93	94	94	93	1	0.959	0.604	0.169
Final	168	171	170	168	1	0.153	0.019	0.128
ADG, kg								
0–55 days	0.81	0.83	0.83	0.81	0.01	0.988	0.187	0.018
56–147 days	0.82	0.85	0.84	0.83	0.01	0.097	0.021	0.860
0–147 days	0.82	0.84	0.83	0.82	0.01	0.190	0.026	0.285
G:F								
0–55 days	0.372	0.408	0.395	0.384	0.005	0.961	<0.01	0.022
56–147 days	0.259	0.292	0.276	0.275	0.005	0.114	<0.01	0.684
0–147 days	0.293	0.327	0.312	0.308	0.005	0.232	<0.01	0.211
G/Mcal DE								
0–55 days	0.126	0.127	0.129	0.125	0.001	0.959	0.282	0.020
56–147 days	0.088	0.091	0.090	0.089	0.001	0.118	0.017	0.710
0–147 days	0.099	0.102	0.101	0.100	0.001	0.232	0.028	0.226

Cometa: hulled normal-amylose; Alamo: hulless low-amylose; BW: body weight; ADG: average daily gain; G:F: ratio between weight gain and feed intake; G/Mcal DE: gain per megacalorie of digestible energy.

Table 4. Carcass characteristics of pigs fed diets based on two different barley varieties with or without non-starch polysaccharides degrading enzymes.

	Barley		Sex			*p* Value		
Item	Cometa	Alamo	Female	Castrated male	SEM	Enzyme	Barley	Sex
Carcass weight[a], kg	138	142	141	140	1	0.403	<0.01	0.234
Dressing percentage	82.6	83.1	82.8	82.9	0.2	0.256	0.115	0.696
Longissimus dorsi thickness, mm	64	65	65	65	1	0.330	0.478	0.829
Back fat thickness, mm	26	27	26	28	1	0.381	0.357	0.068
Lean meat, %	53.5	53.1	53.7	52.9	0.2	0.387	0.349	0.060
Thigh weight[b], kg	34.6	35.6	35.4	34.8	0.2	0.606	0.028	0.150
Thigh yield, %	25.0	25.1	25.1	24.9	0.1	0.878	0.639	0.343
Thigh chilling losses, %	1.80	1.63	1.75	1.68	0.03	0.257	<0.01	0.178
pH 45-min *post mortem*								
Semimembranosus muscle	6.30	6.25	6.32	6.23	0.04	0.310	0.418	0.219
Biceps femoris muscle	6.27	6.30	6.36	6.20	0.03	0.400	0.532	0.209
pH 24-h *post mortem*								
Semimembranosus muscle	5.69	5.75	5.74	5.71	0.02	0.706	0.105	0.441
Biceps femoris muscle	5.75	5.76	5.74	5.77	0.02	0.467	0.987	0.519

Cometa: hulled normal-amylose; Alamo: hulless low-amylose.
[a]Cold carcass.
[b]Sum of the weight of both hot thighs.

($p = 0.028$) weights, and decreased thigh chilling losses ($p < 0.01$) compared with the pigs fed the Cometa diet.

Fresh thigh quality

Parameters of fresh thigh quality are shown in Table 5. There were no barley × enzyme, barley × sex and barley × enzyme × sex interactions nor an enzyme effect on all the measured parameters. A sex effect was observed on a* and C values ($p < 0.01$) of *biceps femoris* with higher values in castrated males compared with females. A sex effect was also found on fatty acid composition and iodine value of subcutaneous fat. In particular, the subcutaneous fat of females was characterised by a higher polyunsaturated fatty acid (PUFA) level ($p = 0.017$), mainly due to the higher contents of C 18:2*n-6* ($p = 0.017$) and C 18:3*n-3* ($p = 0.037$) fatty acids, and as a result by a higher iodine value and a lower saturated fatty acids (SFA)/PUFA ratio ($p = 0.028$) than the subcutaneous fat of castrated males. A barley effect was found on color and fatty acid composition of subcutaneous fat. In particular, the pigs fed the Cometa diet had subcutaneous fat characterised by a higher H value ($p = 0.036$), higher levels of C 18:1*n-9cis* ($p < 0.01$), C 18:3*n-3* ($p = 0.024$) and monounsaturated fatty acids ($p < 0.01$), and a higher SFA/PUFA ratio ($p < 0.01$) than the pigs fed the Alamo diet. Moreover, the subcutaneous fat from pigs fed the Cometa diet had lower contents of C 18:2*n-6* fatty acid and PUFA ($p < 0.01$), and tended to had a lower iodine

Table 5. Fresh thigh color and subcutaneous fat quality of pigs fed diets based on two different barley varieties with or without non-starch polysaccharides degrading enzymes.

	Barley		Sex			*p* Value		
Item	Cometa	Alamo	Female	Castrated male	SEM	Enzyme	Barley	Sex
Color of *biceps femoris*								
Lightness (L*)	40.78	40.40	40.76	40.42	0.29	0.636	0.556	0.593
Redness (a*)	8.63	8.55	8.09	9.09	0.18	0.842	0.765	<0.01
Yellowness (b*)	1.88	1.75	1.79	1.84	0.14	0.696	0.682	0.865
Chroma (C)	8.90	8.74	8.33	9.31	0.17	0.831	0.536	<0.01
Hue angle (H)	12.74	10.79	12.40	11.14	0.95	0.883	0.353	0.544
Color of subcutaneous fat								
Lightness (L*)	84.45	84.42	84.35	84.52	0.14	0.596	0.925	0.606
Redness (a*)	1.74	1.70	1.74	1.69	0.06	0.166	0.747	0.699
Yellowness (b*)	2.16	1.67	2.03	1.80	0.14	0.288	0.087	0.393
Chroma (C)	2.80	2.45	2.74	2.51	0.13	0.164	0.166	0.357
Hue angle (H)	50.73	43.02	47.38	46.38	1.79	0.480	0.036	0.764
Fatty acids, % per total fatty acids								
C 14:0	1.21	1.26	1.24	1.23	0.02	0.244	0.199	0.791
C 16:0	23.75	23.64	23.58	23.82	0.20	0.198	0.784	0.563
C 16:1	1.63	1.57	1.58	1.62	0.02	0.349	0.263	0.431
C 18:0	17.60	17.72	17.61	17.72	0.11	0.603	0.643	0.666
C 18:1*n-9cis*	43.28	41.97	42.62	42.63	0.22	0.254	<0.01	0.972
C 18:1*n-11cis*	0.68	0.72	0.64	0.76	0.04	0.314	0.603	0.097
C 18:2*n-6*	9.57	10.81	10.43	9.94	0.19	0.349	<0.01	0.017
C 18:3*n-3*	0.57	0.54	0.57	0.54	0.01	0.223	0.024	0.037
C 20:1	0.98	1.01	0.98	1.01	0.02	0.973	0.483	0.494
SFA	42.80	42.85	42.65	42.99	0.16	0.181	0.892	0.326
MUFA	46.58	45.27	45.83	46.03	0.22	0.406	<0.01	0.507
PUFA	10.62	11.88	11.51	10.99	0.20	0.306	<0.01	0.017
SFA/PUFA	4.04	3.61	3.71	3.94	0.08	0.243	<0.01	0.028
Iodine value	58.59	59.49	59.7	58.4	0.30	0.305	0.092	0.028

Cometa: hulled normal-amylose; Alamo: hulless low-amylose; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; SFA/PUFA: ratio between saturated fatty acids and polyunsaturated fatty acids.

value ($p = 0.092$) than the subcutaneous fat from pigs fed the Alamo diet.

Discussion

In the current study, the effect of Cometa or Alamo barley inclusion at 85% level in diets for heavy growing-finishing pigs was evaluated on growth performance, carcass characteristics and fresh thigh quality. Taking into account that Cometa is a traditional hulled barley variety and Alamo is a hulless barley variety rich in β-glucans, the effect of NSP enzyme complex addition was also studied. In our experiment the supplementation with β-glucanase and xylanase did not improve the Cometa and Alamo diets in terms of pig growth performance, carcass characteristics and fresh thigh quality. In the literature there is a lack of information on the use of NSP-degrading enzymes in diets for growing-finishing pigs. The most of the studies focuses on the use of exogenous NSP enzymes in diets for weaned piglets, as especially piglets do not produce enzymes capable of degrading NSP (Kerr & Shurson 2013). Li et al. (2004) and Fan et al. (2009) reported that the addition of β-glucanase and xylanase to barley-based diets improved growth performance of piglets. However, the need for exogenous NSP enzyme supplementation of barley-based diets on weaned piglets can depend on the used barley variety (Prandini et al. 2014). Based on the latter, no NSP enzyme complex addition is needed if traditional hulled barley (i.e. Cometa) or hulless barley with high β-glucan content and increased starch digestion potential (i.e. Alamo) are used in diets both for weaned piglets (Prandini et al. 2014) and, on view of results of the current study, also on heavy growing-finishing pigs. Instead, the use of the NSP enzyme complex could improve feed efficiency of pig diets based on hulless normal-amylose barley with positive effects on growth performance (Prandini et al. 2014).

Throughout the study, the pigs fed the Alamo diet had greater feed efficiency, and as a result grew faster and gained greater final BW than the pigs fed the Cometa diet. These results could be explained by the different contents of fibre and total starch along with the type of starch of the two experimental diets. The Alamo diet was characterised by a numerically higher total starch content and starch digestion potential (expressed as pGI), and a lower RS content compared with the Cometa diet. Different responses in productive performance can arise from pigs fed diets based on starch sources with great differences in starch digestibility (Giuberti et al. 2014). In agreement with previous studies (Li et al. 2007; Regmi et al. 2011; Prandini et al. 2014; Prandini, Sigolo, Giuberti, et al.

2015), in our condition the starch source with low contents of amylose and RS, and high starch digestion potential increased the feed efficiency and growth of pigs. In addition, because the Alamo diet was based on a hulless barley variety, it was characterised by a numerically lower content of crude fibre compared with the Cometa diet. As a large proportion of crude fibre of barley is contained in the hull fraction (Bell et al. 1983), the absence of the hull in barley would seem to improve the nutritive value of the Alamo diet and, along with the factors above described, promoting the feed efficiency and growth of pigs. It is interesting to highlight that in our previous study on heavy growing-finishing pigs (Prandini, Sigolo, Giuberti, et al. 2015), a higher feed efficiency was observed *vice versa* when feeding hulled barley-based diet (i.e. Cometa) than hulless barley-based diets (i.e. Astartis and Alamo). An underestimation of the energy content of hulled barley in the diet formulation resulting in a greater daily feed intake was hypothesised. The present findings suggest that Perez et al.'s (1980) equation applied in the current study to calculate the DE of the 2 barley varieties could be more appropriate than the Fairbairn et al.'s (1999) Equation 1 used in the previous study (Prandini, Sigolo, Giuberti, et al. 2015).

The literature reports contrasting results about the effect of starch type on carcass characteristics (Camp et al. 2003; Shelton et al. 2004; Doti et al. 2014; Prandini, Sigolo, Giuberti, et al. 2015). These discrepancies could be addressed to the different experimental conditions used such as growth phase of pigs, level of inclusion of high glycemic index starch sources, and type of starchy ingredients. In agreement with Camp et al. (2003), our data showed an increase in the carcass weight but no effects on fatness or leanness when feeding the low-amylose barley based diet (i.e. Alamo diet). This result was also consistent with the highest final BW found in the pigs fed the Alamo diet. In addition, the carcass of these pigs was characterised by a higher thigh weight and was less depreciated for thigh chilling losses compared with the carcass of pigs fed the Cometa diet. At present, there is enough evidence that fibre can affect carcass composition of pigs (Bach Knudsen 2011). In agreement with our findings, Just (1982, 1984) found lighter BW and carcass weight for pigs fed greater amounts of fibre. However, current results were in contrast with previous data reporting no effects of the starch type and fibre level on pig carcass characteristics (Prandini, Sigolo, Giuberti, et al. 2015). Nevertheless, in the Prandini, Sigolo, Giuberti, et al.'s (2015) study there was a high variability of the carcasses data which could have reduced the ability of detecting differences among treatments.

The hardness is an important characteristic defining the technological quality of pig fat and is related to the ratio between SFA and PUFA levels in the fat (Wood et al. 2003). If the SFA concentration increases, the fat becomes firmer, *vice versa* an increase in the PUFA concentration yields a softer fat and more susceptible to oxidative modification which can generate off-odors and flavors, and color changes (Wood et al. 2003; Nishioka & Irie 2006). The Cometa diet determined a decrease of the PUFA (mainly C 18:2*n-6* fatty acid) content, in favor of a higher content of MUFA (mainly C 18:*1n-9cis*), in the subcutaneous fat of fresh thighs compared with the Alamo diet. As a result, the SFA/PUFA ratio was higher and the iodine value tended to be lower for the subcutaneous fat of the pigs fed the Cometa diet than for the subcutaneous fat of the pigs fed the Alamo diet. However, the subcutaneous fat of fresh thighs obtained from the pigs fed both Cometa and Alamo diet had iodine value and C 18:2n-6 fatty acid percentage within the limits (70% and 15%, respectively) fixed by the production protocols of the Parma and San Daniele hams (Consorzio del Prosciutto di Parma 2015; Consorzio del Prosciutto di San Daniele 2015), and a SFA percentage higher than the minimum value of 41% reported for acceptable fat firmness (Hugo and Roodt 2007). Moreover, no appreciable differences were observed in the color of subcutaneous fat and *biceps femoris* from pigs fed the Cometa and Alamo diets. In agreement with current results, Prandini, Sigolo, Gallo, et al. (2015) found that a diet based on a hulled barley variety (Cometa) rather than on a hulless low-amylose barley variety (Alamo) improved fat unsaturation level of meat products although with no appreciable differences in color and sensory properties.

Conclusions

Benefits may result from the use of barley in pig rearing. As barley is a drought-tolerant crop and therefore requires less or no irrigation water, its production could have a low environmental impact particularly in countries where the climate is becoming warmer and drier (Majumdar 2013; Prandini, Sigolo, Gallo, et al. 2015; Prandini, Sigolo, Giuberti, et al. 2015) and water represent a limited source. Our current findings showed that the barley included in the pig diet can affect the growth performance and carcass characteristics. In particular, feeding hulless low-amylose barley to growing-finishing pigs can be valuable to promote the growth performance and carcass characteristics. Moreover, no NSP enzyme complex addition is needed when hulled normal-amylose barley or hulless low-amylose barley are used in diets for heavy growing-finishing pigs. The unsaturation level of pig's subcutaneous fat can be improved by feeding hulled normal-amylose. However, the required quality for subcutaneous fat of fresh thighs for the production of PDO Italian dry-cured meat products can be achieved both with hulled normal-amylose and hulless low-amylose barley without affecting color of *biceps femoris* or subcutaneous fat. Lastly, the inclusion of hulless low-amylose barley at 85% level would allow the exclusion of soybean meal (48% crude protein) in the diet formulation for growing-finishing pigs with advantages in terms of feed cost and benefits for the environment (Eriksson et al. 2005; Prandini et al. 2011).

Disclosure statement

The authors declare that no financial interest or benefit are arising from the direct applications of their research.

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