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Growth performance, carcass traits, meat quality and composition in pigs fed diets supplemented with medicinal plants (*Bindens pilosa* L., *Urena lobata* L. and Ramulus cinnamomi) powder

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ABSTRACT. The study was conducted to assess the effects of medicinal plants powder (MP) (60% *Bindens pilosa* L., 30% *Urena lobata* L. and 10% Ramulus cinnamomi) as a feed additive to promote growth performance and improve meat quality in pigs. Seventy-two crossbred pigs [Duroc × (Landrace × Yorkshire)], initial body weight 30.3 ± 1.66 kg, were randomly divided into 4 dietary groups, 3 replicates of 6 pigs each. Each group was randomly allocated to one of four dietary treatments: a basal diet (control diet, T_0) and three experimental diets (T_{20}, T_{40} and T_{60}) based on T_0 diet supplemented with MP at 20, 40 and 60 g/kg of feed. The experiment lasted for 14 weeks, including 2 periods of feeding programmes (weeks 0–7 and 7–14). A reduced average daily feed intake (linear, $P = 0.01$) and a decreased trend in average daily gain (ADG) (linear, $P = 0.08$) were observed in pigs fed diets with 40 and 60 g/kg MP in comparison to the control diet in weeks 0–7. There was no statistical difference in ADG and feed conversion ratio between treatments over the entire trial period. Dietary MP supplementation decreased backfat thickness (quadratic, $P = 0.04$) and cholesterol content (linear, $P = 0.02$; quadratic, $P = 0.01$) in meat. The sensory quality of cooked meat was improved ($P < 0.0001$) by the inclusion of MP. So, dietary MP supplementation could have the potential to improve sensory quality and decrease backfat thickness and cholesterol content in meat without a negative effect on growth rate of pigs and technological quality of pork.

Introduction

A number of medicinal plants have received more attention from livestock scientists as potential alternative sources to antibiotics for raising animals due to their beneficial effects on activation of digestive enzymes secretion, immune stimulation, antibacterial, antiviral and antioxidant properties (Zhou et al., 2013; Ahmed et al., 2016; Dula et al., 2018; Fan et al., 2019; Luo et al., 2020). Vietnam is one of the tropical countries with a high biodiversity of herbal plant species, accounting for 11% of the 35 thousand different species of herbal plants known worldwide (Vu et al., 2020). For instance, *Bindens pilosa* L., *Urena lobata* L. and Ramulus cinnamomi (*Cinnamomum cassia* Presl.) are widely distributed medicinal plants which are considered as natural feed additives (Matysiak et al., 2012). Phytochemical analyses reported the bioactive components of aerial parts of *B. pilosa* – source of flavonoids and other phenolic compounds (Cortés-Rojas et al., 2013), aerial parts of *U. lobata* –

source of alkaloids and saponins (Pham et al., 2019) and Ramulus cinnamomi – source of *trans*-cinnamaldehyde and its derivatives (Sang-Oh et al., 2013), along with their antimicrobial, antifungal, antioxidant, cholesterol-lowering functions and quality improvement of animal products. Especially, a significant decrease in oxidation susceptibility of animal products owing to phenolic compounds in medicinal plants (Amaral et al., 2018) is likely to improve the sensory quality of meat including shelf life and flavour.

Several recent studies have been conducted to investigate the effects of the supplementation of *B. pilosa*, *U. lobata* and Ramulus cinnamomi alone in the diets and revealed positive effects on animal production parameters (Sang-Oh et al., 2013; Purnomo et al., 2017; Luo et al., 2020). The supplementation of cinnamaldehyde in the finishing pig diet reduced the backfat thickness, improved antioxidant capacity, flavour and taste of pig meat (Jiang et al., 2017; Luo et al., 2020). Dietary supplementation of *U. lobata* decreased blood glucose level, and increased insulin level in rats and rabbits (Omonkhua and Onoagbe, 2011; Islam et al., 2015; Purnomo et al., 2017). *B. pilosa* showed not only strong antimicrobial and antioxidant activity (Deba et al., 2008) but also antidisentery action in growing pigs (González and Ly, 2001), or anti-coccidial potential in chickens (Yang et al., 2015). Moreover, broiler chickens fed diet supplemented with 0.5% *B. pilosa* had beneficial effects on growth performance *via* modulation of gut bacteria (Chang et al., 2016).

Nevertheless, to the best of our knowledge, the effects of the medicinal plants combination (*B. pilosa, U. lobata* and Ramulus cinnamomi) on growth performance, carcass quality parameters of pork have not yet been studied. A mixture of these medicinal plants is expected to exert beneficial effects from chemical and pharmaceutical properties. Therefore, the present study aimed to assess the growth performance, carcass parameter, nutrient quality and sensory quality of pork from growing-finishing pigs fed diets supplemented with increasing inclusions of medicinal plant mixture (*B. pilosa, U. lobata* and Ramulus cinnamomi) at long-term manner.

Material and methods

The protocol of this research was reviewed and approved by the Animal Ethics Committees of Vietnam National University of Agriculture (VNUA), Vietnam (Approval No: VNUA-2020/04).

Sources of medicinal plants

Aerial parts of *B. pilosa* and *U. lobata*, which grow naturally, were harvested during the vegetative growth phase from Luong Son village of Hoa Binh province, Vietnam. Ramulus cinnamomi also was harvested from a forest garden of Hoa Binh province Vietnam. Each plant was cleaned and then manually broken into pieces. Then *B. pilosa* (herbaceous plant), *U. lobata* (semi-woody plant) and Ramulus cinnamomi (woody plant) were separately dried in a mechanical drier at 50, 55 and 60 °C, respectively for 8 h. After drying, they were separately stored in air-tight bags. The dried plants were ground into a fine powder and proportionally mixed as a powder (MP) containing 60% *B. pilosa*, 30% *U. lobata* and 10% Ramulus cinnamomi before being incorporated into diets. This ratio of the medicinal plants mixture (60:30:10) was determined by availability, phytochemicals and the recommendation of the traditional experiences.

Animals, diets, experimental design

This study was conducted from June to October 2020 at the experimental farm of the Faculty of Animal Science, VNUA. Seventy-two crossbred growing pigs [Duroc × (Landrace × Yorkshire)], initial body weight (IBW) 30.3 ± 1.66 kg (mean ± standard deviation), were used in the study. The pigs were divided into four dietary treatments according to equal IBW and sex. Each treatment had 3 replicate pens with 6 pigs (3 barrows and 3 gilts) per pen (2.5 × 3.3 m) installed along with one automatic feeding and 2 automatic drinking nipples. The temperature in the pig house ranged between 27 and 30 °C, while relative humidity was maintained at 70–85% during the whole experimental period. The animals were fed one of four diets: a basal diet (control diet, T_0) and 3 experimental diets – T_{20}, T_{40}, T_{60} – based on T_0 diet supplemented with MP at a dose of 20, 40 and 60 g/kg, respectively, for 14 weeks including 2 periods of feeding programmes (weeks 0–7 and 7–14). Pigs were fed *ad libitum* during the whole experimental period and animals always had free access to water by nipple drinkers.

Raw feed ingredients were purchased locally from a feed company. Maize and soybean meal were milled into flour through a 2-mm screen before mixing with other feed ingredients. The complete diets were collected for chemical composition and nutrient value analysis. The composition of the basal diet is shown in Table 1, while nutrient levels of the experimental

Table 1. Ingredients (%, as-fed basis) of the basal diets

Ingredient	Trial period	
	Growing (weeks 1–7; 30–60 kg)	Finishing (weeks 7–14; 61–100 kg)
Maize	33.9	38.6
Soybean meal	13.4	10.2
Fish meal	3.50	2.00
Rice bran	25.0	25.0
Wheat bran	20.0	20.0
Limestone	1.50	1.50
Vitamin-mineral premix[1]	0.50	0.50
Salt	1.00	1.00
Farm-enzyme[2]	0.50	0.50
L-lysine HCl, 98.5%	0.50	0.50
DL-Methionine, 98%	0.20	0.20

[1] contained per kg of premix: mg: $FeSO_4$ 150–200, $ZnSO_4$ 250–300, $MnSO_4$ 150–200, $CuSO_4$ 250–300, biotin 8; g: activity enzyme 100, sufficient carrier 1000; %: coarse sand 2, moisture 10; [2] contained per kg: CFU/g: *Saccharomyces boulardii* 10^9–2×10^{10}, *Saccharomyces fibuliger* 10^6–10^{10}, *Lactobacillus acidophilus* 10^9–3×10^9, *Candida tropicolis* 10^5–10^8; moisture (max) 10%

diets which met the recommended requirements for grower-finisher pigs (NRC, 2012) are presented in Table 2. Chemical compositions of diets were analysed for dry matter, crude protein, ether extract, ash, crude fibre, neutral detergent fibre, calcium and phosphorus according to the Association of Analytical Chemists methods (AOAC, 1990) (methods 934.01, 954.01, 920.39, 942.05, 962.06, 973.18, 935.13 and 965.17, respectively). The bomb calorimeter (mode E2k, CAL2k, Johannesburg, South Africa) was used for gross energy determination.

Sampling and measurements

Pig performance. Animals were weighed at the beginning (day 0) (IBW), at week 7 (final body weight 1; FBW1) and at the end of the experiment (week 14, FBW2). Average daily dry matter feed intake (ADFI, kg/pig/day), average daily weight gain (ADG, g/pig/day) and feed conversion ratio (FCR, feed/weight gain, kg/kg) were estimated for each replicate, diet, period and over the entire trial period.

Carcass parameters. At the end of the experiment, twenty-four pigs (six pigs per treatment, one barrow and one gilt per pen with the closest weight to the average BW in pen and sex) were slaughtered by electrical head-only stunning followed by exsanguination. The basic process of slaughtering pigs was carried out according to the guidelines for estimating carcass parameters from Vietnamese National Standards (TCVN, 1984; #3899-84). Hot carcass weight (HCW, kg), killing-out percentage (KOP, %), carcass weight (CW, kg), dressing percentage (DP, %) and backfat thickness (BFT, mm) were determined as described in the previous study (Oanh et al., 2019). Internal organs including heart, liver, kidney and spleen were collected separately and weighed as previously described (Oanh et al., 2020).

After slaughter, *longissimus lumborum* muscle (LLM) samples were collected between the last three ribs of the left side of each carcass of the test pigs, and then each was cut into 5 subsamples (about 200 g per sample). Subsamples were separately weighed and placed in marked plastic zip-lock bags. The two of them were kept at 4 °C for technological quality evaluation at 24 and 48 h *post-mortem*. The remaining ones had immediately measured chemical composition, cholesterol content, omega-3 fatty acids content and sensory assessment.

Technological properties of *longissimus lumborum* muscle. The raw LLM samples were examined using a portable pH (pH-STAR, Matthäus,

Table 2. Analysed compositions (% DM) and energy values (MJ/kg DM) of the experimental diets

Ingredient	MP	Growing phase				Finishing phase			
		T_0	T_{20}	T_{40}	T_{60}	T_0	T_{20}	T_{40}	T_{60}
Dry matter (DM)	92.4	88.9	88.4	89.1	89.2	88.7	88.9	88.5	88.9
Crude protein	12.7	18.8	18.8	18.6	18.5	16.4	16.5	16.1	16.0
Ether extract	1.63	7.55	7.22	7.26	7.30	7.77	7.63	7.33	7.47
Crude ash	12.3	8.86	8.73	8.80	8.86	7.57	7.72	8.17	7.91
Crude fibre	28.4	5.24	5.89	5.97	6.95	5.14	5.45	5.81	5.93
Neutral detergent fibre	51.4	21.5	23.4	23.1	23.4	17.5	18.3	18.7	18.9
Calcium	1.32	1.39	1.11	1.21	1.18	1.25	1.25	1.19	1.28
Total phosphorus	0.34	0.85	0.79	0.86	0.86	0.91	1.00	0.96	0.86
Gross energy, MJ/kg DM	18.3	18.5	18.5	18.2	18.5	18.8	18.5	18.8	18.3
Metabolizable energy[1], MJ/kg DM	-	13.9	13.8	13.7	13.5	14.5	14.2	14.0	13.9
Lysine[2]	0.89	1.33	1.32	1.31	1.30	1.18	1.17	1.17	1.16
Methionine[2]	0.38	0.54	0.53	0.53	0.53	0.49	0.49	0.49	0.49

MP – medicinal plants powder containing 5.45 mg gallic acid equivalent/g and 16.96 mg quercetin/g DM as polyphenols and flavonoids, respectively; dietary treatments: T_0 – control diet, T_{20}, T_{40}, T_{60} – diets mixed with 2, 4 and 6% of MP, respectively; [1] calculated according to Noblet and Perez (1993); [2] calculated data

Germany) at 45 min, 24 and 48 h *post-mortem*. The other following parameters were determined at 24 and 48 h: lightness (L^*), redness (a^*) and yellowness (b^*) values were estimated in raw LLM slices using the model CR-410 Chroma Meter (Minolta, Osaka, Japan) as previously described (Lee et al., 2011). Drip loss percentages at 24 and 48 h (DL_{24} and DL_{48}) and drip cooking percentage at 24 and 48 h (CL_{24} and CL_{48}) were measured as previously described (Oanh et al., 2019). Shear forces (SF) were measured on the cooked LLM slices by using a Warner-Bratzler shear machine (model 2000D, GR Manufacturing, Manhattan, KS, USA) as previously described (Choi et al., 2014).

Chemical composition, cholesterol content and omega-3 content of *longissimus lumborum* muscle. Dry matter, crude protein, lipids and ash contents of raw LLM samples were analysed according to AOAC (1990). Cholesterol content was measured by using a Shimadzu GC/MS-QP2010 gas chromatography-mass spectrometry (Shimadzu, Kyoto, Japan) according to the steps described previously (Derewiaka and Obiedziński, 2010). The total of omega-3 fatty acids content was analysed using an Agilent 6890 Plus gas chromatography (Agilent Technologies, Palo Alto, CA, USA) equipped with a flame ionized detector and a SP®-2560 capillary GC column following the method previously described (Ding et al., 2017).

Sensory assessment of *longissimus lumborum* muscle. The sensory evaluation was conducted using a previously described method by Fan et al. (2019) with slight modifications. The LLM samples (2 cm wide) were coded individually with different numbers and separately boiled with the same volume of water (water flooded with meat sample) and pots on induction cooktops (1800 W power) for 15 min each. After cooking, the meat slices were cooled at room temperature for 15 min. The samples were then cut into smaller pieces in order to serve to the panellists. Warm water was used to clean the mouth between samples. Sensory evaluation was performed by a trained ten-member panel, consisting of 5 male and 5 female specialists from the Faculty of Food Science and Technology, VNUA, who scored sensory attributes of flavour and taste, tenderness and overall acceptability of cooked LLM meat using a 9-point liking scale (1 – dislike extremely, 2 – dislike very much, 3 – dislike moderately, 4 – dislike slightly, 5 – neither like nor dislike, 6 – like slightly, 7 – like moderately, 8 – like very much, 9 – like extremely).

Data analysis

Experimental data were treated using a PROC MIXED procedure (SAS software, version 9.4, SAS Institute Inc., Cary, NC, USA). The statistical model for the analysis of data included: diets (n = 4; T_0, T_{20}, T_{40} and T_{60}) as a fixed effect, and blocks (n = 3) as a random effect. The experimental unit for the growth parameters was a pen, while pig individuals were used as the experimental unit for carcass characteristics, meat quality, chemical compositions and sensory data. A similar model was used for repeated measurements data on the same experimental unit (panellist measurements) but included the random effect of repetition according to a compound symmetry covariance structure. Linear and quadratic effects of level supplementation of MP were explored using polynomial contrasts. Orthogonal contrasts were used to compare data between pigs fed diets supplemented with MP and pigs fed control diet. The least square means multiple comparisons were tested using Tukey adjustment. Level of significance was determined at $P < 0.05$, and a statistical trend as $0.05 \leq P < 0.10$.

Results

Animal performance

Performances of experimental pigs are shown in Table 3. There were no animal losses during the entire experimental period. Animal IBW was similar among diets ($P = 0.98$). During weeks 0–7, a reduced $ADFI_1$ (linear, $P = 0.01$) and a trend for a decrease in ADG_1 (linear, $P = 0.08$) were observed in growing pigs fed diets supplemented with 40 and 60 g/kg MP in comparison to T_{20} and control groups. During weeks 7–14, MP did not affect FBW_2, ADG_2 and FCR_2 (linear, $P \geq 0.13$). For the entire experimental period, there was no statistical difference (linear, $P \geq 0.21$) between ADG and FCR in pigs fed diets supplemented with MP in comparison to those fed control diet (Table 3).

Carcass parameters

No significant differences were observed in HCW, KOP, CW and DP among diets (Table 4). A significant decrease (quadratic, $P = 0.01$) in BFT was observed in pigs fed diets with increasing MP inclusion, with the lowest value in the group supplemented with 60 g/kg MP. There was no significant difference (linear, $P \geq 0.40$) in heart, kidney, liver and spleen weights between pigs fed MP diets and pigs fed control diet.

Technological properties of *longissimus lumborum* muscle

The pH values (pH_{45}, pH_{24} and pH_{48}), drip losses (DL_{24} and DL_{48}), cooking loss (CL_{24}), shear forces (SF_{24} and SF_{48}) and raw LLM surface colour CIE

Table 3. Feed intake, average daily weight gain and feed conversion ratio in pigs fed diets supplemented with medicinal plants powder

Indices	Dietary treatment[1]				SEM	*P*-value	
	T_0	T_{20}	T_{40}	T_{60}		linear	quadratic
Number of pigs	18	18	18	18			
Initial body weight, kg	30.4	30.3	30.3	30.4	0.40	0.93	0.73
Growing phase (weeks 0–7)							
final body weight, kg	67.8	68.3	66.5	65.3	1.17	0.08	0.45
average daily feed intake, kg/day	1.88[a]	1.87[a]	1.77[ab]	1.68[b]	0.05	0.01	0.49
average daily gain, g/day	762	776	740	712	24.0	0.08	0.38
feed conversion ratio, kg/kg	2.47	2.40	2.39	2.37	0.04	0.10	0.57
Finishing phase (weeks 7–14)							
final body weight, kg	105.8	107.4	106.0	106.6	1.98	0.93	0.80
average daily feed intake, kg/day	2.67	2.71	2.72	2.80	0.10	0.37	0.87
average daily gain, g/day	776	797	806	842	31.6	0.15	0.81
feed conversion ratio, kg/kg	3.43	3.40	3.38	3.32	0.05	0.13	0.81
Overall							
average daily gain, g/day	769	787	773	777	20.7	0.92	0.74
feed conversion ratio, kg/kg	2.95	2.90	2.91	2.88	0.03	0.21	0.71

[1] dietary treatments: T_0 – control diet, T_{20}, T_{40}, T_{60} – diets mixed with 2, 4 and 6% of medicinal plants powder, respectively; SEM – standard error of the mean; [a,b] – means with different superscripts in the same row are significantly different at $P < 0.05$

Table 4. Carcass parameters and internal organs in pigs fed diets supplemented with medicinal plants powder

Indices	Dietary treatment[1]				SEM	*P*-value	
	T_0	T_{20}	T_{40}	T_{60}		linear	quadratic
Number of pigs	6	6	6	6			
Carcass characteristics							
final body weight, kg	106.5	108.7	107.3	106.7	2.12	0.46	0.79
hot carcass weight, kg	85.2	87.7	86.3	85.6	1.74	0.31	0.79
killing-out percentage, %	80.0	80.7	80.5	80.3	0.42	0.28	0.97
carcass weight, kg	74.8	76.6	75.6	75.7	1.51	0.47	0.97
dressing percentage, %	70.3	70.5	70.4	71.0	0.41	0.95	0.42
backfat thickness, mm	19.0[a]	16.6[ab]	15.5[ab]	14.3[b]	0.92	0.15	0.01
Internal organs, % body weight							
heart	0.41	0.39	0.38	0.40	0.01	0.49	0.16
kidney	0.32	0.30	0.32	0.33	0.01	0.40	0.11
liver	1.55	1.52	1.54	1.57	0.06	0.85	0.63
spleen	0.15	0.14	0.15	0.15	0.01	0.94	0.51

[1] dietray treatments: T_0 – control diet, T_{20}, T_{40}, T_{60} – diets mixed with 2, 4 and 6% of medicinal plants powder, respectively; SEM – standard error of the mean; [a,b] – means with different superscripts in the same row are significantly different at $P < 0.05$

(L^*_{24}, a^*_{24}, b^*_{24}; L^*_{48}, a^*_{48}, b^*_{48}) of LLM were not significantly different (linear, $P \geq 0.11$) between pigs fed diets supplemented with MP in comparison to those fed control one (Table 5).

Chemical composition, cholesterol content and total omega-3 content of meat

Dry matter, ash lipids and protein of the raw LLM were not statistically different (linear, $P \geq 0.55$) among diets. However, in pigs fed diets supplemented with MP significantly (linear, $P = 0.02$; quadratic, $P = 0.01$) decreased cholesterol level was observed in comparison to control animals. Omega-3 fatty acids content was statistically not affected (linear, $P = 0.55$) by dietary MP (Table 6).

Sensory assessment

Sensory characteristics of cooked LLM meat with increasing levels of MP after cooking are shown in Table 7. Meat from animals fed diets with increasing inclusion of MP was characterised by significantly improved (linear, $P < 0.0001$) sensory properties of flavour, taste, tenderness and overall acceptability. In addition, a trend for quadratic increase ($P = 0.05$) for acceptability was measured in cooked meat from pigs fed diets with MP inclusion.

Table 5. Technological quality parameters of pork in pigs fed diets supplemented with medicinal plants powder

Indices	Dietary treatment[1]				SEM	*P*-value	
	T_0	T_{20}	T_{40}	T_{60}		linear	quadratic
Number of pigs	6	6	6	6			
pH							
pH_{45}	6.31	6.35	6.32	6.32	0.03	0.50	0.82
pH_{24}	5.53	5.51	5.52	5.50	0.03	0.90	0.69
pH_{48}	5.51	5.50	5.51	5.49	0.02	0.88	0.68
Drip loss, %							
DL_{24}	1.45	1.33	1.31	1.33	0.22	0.71	0.77
DL_{48}	1.79	1.67	1.73	1.72	0.21	0.71	1.00
Cooking loss, %							
CL_{24}	26.1	25.6	25.6	26.0	1.24	0.74	0.98
CL_{48}	27.2	26.8	27.7	26.8	0.95	0.94	0.79
Shear force, N							
SF_{24}	38.9	36.1	35.5	34.0	1.80	0.41	0.14
SF_{48}	40.5	36.8	34.9	35.4	2.73	0.35	0.22
Meat colour CIE							
L^*_{24}	52.6	53.4	54.0	56.1	1.40	0.94	0.16
a^*_{24}	11.9	12.8	13.1	13.1	0.45	0.22	0.12
b^*_{24}	5.19	6.07	6.14	6.26	0.34	0.11	0.11
L^*_{48}	54.7	55.7	56.8	56.4	1.33	0.56	0.29
a^*_{48}	12.9	13.1	12.7	12.9	0.46	0.91	0.63
b^*_{48}	6.10	6.43	6.75	6.60	0.33	0.43	0.24

[1] dietary treatments: T_0 – control diet, T_{20}, T_{40}, T_{60} – diets mixed with 2, 4 and 6% of medicinal plants powder, respectively; SEM – standard error of the mean; pH at 45 min, 24 h and 48 h (pH_{45}, pH_{24}, and pH_{48}); drip loss at 24 h and 48 h (DL_{24} and DL_{48}); cooking loss at 24 h and 48 h (CL_{24} and CL_{48}); shear force at 24 h and 48 h (SF_{24} and SF_{48}); CIE: L*, a*, b* (L* = black (0) to white (100), a* = green (−) to red (+) colour scale, b* = blue (−) to yellow (+) colour scale) at 24 h and 48 h (L^*_{24}, L^*_{48}, a^*_{24}, a^*_{48}, b^*_{24}, b^*_{48})

Table 6. Chemical composition, and cholesterol and omega-3 content of meat in finisher pigs fed diets supplemented with medicinal plants powder

Indices	Dietary treatment[1]				SEM	*P*-value	
	T_0	T_{20}	T_{40}	T_{60}		linear	quadratic
Number of pigs	6	6	6	6			
Chemical composition, %							
dry matter	27.2	27.5	27.9	27.9	0.38	0.68	0.15
ash	1.45	1.45	1.39	1.41	0.03	0.80	0.12
lipids	2.51	2.49	2.45	2.26	0.19	0.88	0.49
protein	22.7	23.0	23.3	23.4	0.22	0.55	0.05
Cholesterol and omega-3 contents, mg/100 g							
cholesterol	60.4^{a}	54.6^{b}	52.9^{bc}	49.2^{c}	1.45	0.02	0.01
total omega-3	18.0	20.3	20.0	21.0	2.11	0.55	0.53

[1] dietary treatments: T_0 – control diet, T_{20}, T_{40}, T_{60} – diets mixed with 2, 4 and 6% of medicinal plants powder, respectively; SEM – standard error of the mean; $^{a-c}$ – means with different superscripts in the same row are significantly different at $P < 0.05$

Table 7. Sensory characteristics of meat in finisher pigs fed diets supplemented with medicinal plants powder

Indices	Dietary treatment[1]				SEM	*P*-value	
	T_0	T_{20}	T_{40}	T_{60}		linear	quadratic
Number of pigs	6	6	6	6			
Flavour	7.28^{b}	7.38^{b}	8.10^{a}	8.10^{a}	0.08	<0.0001	0.61
Taste	7.28^{c}	7.45^{c}	7.93^{b}	8.32^{a}	0.07	<0.0001	0.13
Tenderness	7.42^{b}	7.63^{b}	7.80^{a}	8.10^{a}	0.09	<0.0001	0.85
Acceptability	7.48^{c}	7.83^{b}	8.30^{a}	8.35^{a}	0.07	<0.0001	0.05

[1] dietary treatments: T_0 – control diet, T_{20}, T_{40}, T_{60} – diets mixed with 2, 4 and 6% of medicinal plants powder, respectively; SEM – standard error of the mean; $^{a-c}$ – means with different superscripts in the same row are significantly different at $P < 0.05$

Discussion

Animal performance. This is the first study to evaluate the effects of medicinal plants mixture (*B. pilosa*, *U. lobata* and Ramulus cinnamomi) on animal performance and pork quality. In the present work, in pigs fed diets supplemented with the inclusion of MP there was no significant effect on FBW, ADG and FCR when compared to the control group during the entire experimental period. Some previous studies have been conducted to evaluate the effects of different blends of medicinal plants on the production parameters of growing-finishing pigs; however, the obtained results were not always consistent. For example, a recent finding (Hanczakowska et al., 2015) reported that growth performance of finishing pigs fed diet supplemented with medicinal extract combination of *Salvia officinalis*, *Urtica dioica, Melissa officinalis* and *Echinacea purpurea* was unaffected when compared to the control diet. Likewise, Ahmed et al. (2016) reported that in growing-finishing pigs fed diets supplemented with natural herb combination (pomegranate, *Ginko biloba* and licorice) there was no significant effect on FBW and ADG observed in comparison to animals receiving control diet, but ADFI decreased and FCR increased. However, in another study (Yan et al., 2011), it was demonstrated that growing pigs fed diets supplemented with medicinal extract (buckwheat, thyme, curcuma, black pepper and ginger) had enhanced ADG and ADFI but not FCR. Similarly, Kwon et al. (2005) exposed that herbal extract supplementation (Artemisia, Acanthopanax and garlic) in diet for growing-finishing pigs improved their growth performance. Moreover, Liu et al. (2008) reported that supplementation of a blend of herbal extracts (Biosun®) in finishing pig diet enhanced ADG and insulin-like growth factor-I level, decreased serum malondialdehyde content and FCR, and unaffected ADFI. The contradictory results regarding growth performance responses to medicinal plants could be expected owing to contextual parameters including species, physical and pharmacological properties, age of the plant, plant parts used, harvest time, geographical origin, processing method, sense of taste and various dosage used (Wenk, 2003; Hashemi and Davoodi, 2011; Lei et al., 2018). In addition, physiological growing stages of animals, IBW, experiment lasting, and housing conditions may respond differently to medicinal plants supplementation (Hanczakowska et al., 2015; Ranucci et al., 2015) nettle, lemon balm and coneflower. In the current study, in the first period (weeks 0–7) pigs fed diet supplemented with 20 g/kg MP had slightly improved ADG and unaffected ADFI, while in pigs fed diets supplemented with MP at a dose of 40 and 60 g/kg ADFI tended to decrease in comparison to those fed control diet. This may suggest that it is the organoleptic properties of MP, e.g., bitter taste of *B. pilosa*, that are responsible for the reduction of ADFI with increasing levels of MP supplementation in the diet. Such a result is consistent with the previous study of Baldwin (1976) who demonstrated that the sense of taste was an important factor in determining the selection of feed by pigs. However, the decrease in ADFI was not significant during the finisher period implying that the pigs may become accustomed to MP. The results in this study showed a trend for linear decrease in ADG in growing phase and a numerical increase in ADG in finishing phase with inclusion levels of MP. However, the shift in ADG (ADG finishing – ADG growing) was significant. One reason for these observations could arise from the presence of complex plant polyphenols in the medicinal plant combination which are described to reduce slightly the palatability and feed intake (Ahmed et al., 2016) during growing phase, in contrast to finishing phase when pigs are well adapted to the diet.

Carcass parameters. In the current study, KOP and DP were not significantly different in pigs fed diets supplemented with MP and pigs fed control diet. However, BFT decreased with the increasing level of MP dietary supplementation, which is consistent with the previous studies on natural herb combination (pomegranate, *Gingko biloba* and licorice) (Ahmed et al., 2016) and cinnamaldehyde alone (Luo et al., 2020). This is probably associated with high flavonoids content in the medicinal plants mixture that could alter the intestinal lipid metabolism by decreasing lipogenesis and stimulation of fatty acid β-oxidation, thereby reducing BFT production (Wang et al., 2014).

Technological properties of *longissimus lumborum* muscle. The pH value of pig meat *post-mortem* is an important indicator of quality evaluation as it is related to surface colour, water holding capacity, tenderness and shelf-life of meat. Ultimate pH values of normal pork range between 5.4 and 5.8 (Monin, 2003). In this study, no dietary effects on pH values at 45 min, 24 and 48 h were recorded, and these pH values were within the normal range. Overall meat quality was within the normal range of meat classification as described previously (Lengerken and Pfeiffer, 1987). Lack of effects of dietary MP supplementation on DL and CL at 24 and 48 h was observed in the present study, which is consistent with the similar findings confirmed by the results of previous studies on some different medicinal plants (Janz et al., 2007; Ranucci et al., 2015). Dietary MP supplementation did not significantly influence the surface colour of fresh meat (L*, a* and b*) at 24 and 48 h. Additionally, there was indicated, although not significantly, a decreased trend for shear forces in pigs fed diets with increasing MP inclusion, which is in agreement with the result reported previously by Luo et al. (2020) who noted that medicinal plant supplementation decreased shear force in LLM leading to softer muscle and better taste.

Chemical composition, cholesterol content and total omega-3 content of meat. In the current work, dietary MP supplementation did not affect dry matter, ash, lipids and protein contents in LLM of finishing pigs. However, dietary MP inclusion significantly decreased the cholesterol content in pig meat, even in blood serum (data not shown), which may have been due to the presence of flavonoids in medicinal plants (Zarrouki et al., 2010; Ahmed et al., 2016). Plant flavonoids could form insoluble complexes with cholesterol in intestinal digesta and inhibit the absorption capacity of endogenous and exogenous cholesterol in animal intestine (Rao and Gurfinkel, 2000; Ahmed et al., 2016).

Sensory evaluation of *longissimus lumborum* muscle. It was found that dietary MP improved sensory characteristics of cooked LLM by higher scores for studied indices in comparison to the control meat, which meets the needs of today's consumer. These results are in agreement with previous studies on different medicinal plants (Jang et al., 2008; Mohamed et al., 2011; Hanczakowska et al., 2015). A recent study (Luo et al., 2020) demonstrated an improvement in meat flavour and taste from pigs fed diets supplemented with cinnamaldehyde. Similarly, Yan (2014) reported that supplementation of star anise extract into pork products improved meat colour, flavour, taste and acceptability in comparison to the control meat. Moreover, pigs fed medicinal extracts had more polyunsaturated fatty acids proportion in intramuscular fat which may contribute to the improvement of flavour and taste of pork (Hanczakowska et al., 2015). In addition, medicinal plants modulated intestinal microbiota which may inhibit skatole production leading to improve sensory quality of pork (Claus et al., 2003). Thus, in the present study, improving sensory properties could be due to the changes in compounds as mentioned above in pig meat.

Conclusions

Along with increasing supplementation levels of medicinal plants powder (MP) into pig diets during the growing phase (weeks 0–7), a decreased trend in growth performance parameters, but no differences in these parameters during the finisher phase (weeks 7–14) and over the entire experimental period were observed. This may be due to the compensatory growth phenomenon associated with the progressive adaptation of animals to the feed additive. Dietary MP supplementation improved sensory quality, decreased backfat thickness and cholesterol content of pork but did not change technological quality parameters of meat. Nevertheless, further and deeper investigations are needed to validate potential relationships between fatty acid composition and antioxidant capacity of pig meat, which are related to sensory quality of meat from pigs fed diets supplemented or not with MP.

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Conflict of interest

The authors declare that there is no conflict of interest.

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