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Meat yield and quality characteristics of Woori heukdon pigs as affected by dietary amino acids and chromium supplementation

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Abstract

This study aimed to assess the effect of combined dietary supplementation with amino acids and chromium on carcass traits, meat yield and quality properties of finishing Woori heukdon (WHD) pigs. For this purpose, forty same-age WHD piglets were equally assigned into control and experimental groups (n = 20 per group). The control group were received a basal diet while, the experimental group were received a basal diet supplemented with additional 4% lysine, isoleucine, methionine, threonine, valine and tryptophan during growing phase (30–65 kg body weight), and a basal diet supplemented with 0.1% (w/w) chromium picolinate during finishing period. The pigs were fed ad libitum with the diets until they reached a common market weight of around 110 kg. The animals were slaughtered and assessed for carcass traits and composition, and meat quality of loin, ham and belly cuts. Results showed that no differences in the live weight, carcass weight and total meat yield occurred between control and experimental groups (p–> 0.05). The dietary supplementations significantly increased the intramuscular fat content of the loin and ham cuts, and decreased the fat content of belly cut ($p < 0.05$). No differences in the meat quality (e.g., pH and color) occurred between the control and experimental diets ($p > 0.05$). Noticeably, the dietary supplementation reduced the concentration of polyunsaturated fatty acids (PUFA)-derived unpleasant aldehydes, and increased the number and quantity of Maillard reaction-derived pleasant aroma volatiles. It is suggested that dietary supplementation with the amino acids and chromium could be used to improve the meat quality property of WHD pigs.

Keywords: Woori heukdon, Dietary Supplementation, Intramuscular fat, Meat quality

INTRODUCTION

Perhaps it is known that the deposition of fat in meat animals in general and pigs in particular is important.

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Competing interests
No potential conflict of interest relevant to this article was reported.

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Availability of data and material
Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions
Conceptualization: Hoa VB, Cho SH.
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Formal analysis: Song DH.
Methodology: Hoa VB, Min YJ, Song DH, Kim YS.
Software: Kim HW, Moon SS.
Validation: Cho SH.
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Ethics approval and consent to participate
The experimental protocols for this research were reviewed and approved by the Institutional Animal Care and Use Committee at the National Institute of Animal Science (NIAS-2020-437).

However, meat producers are faced with a paradox in that the site of fat deposition determines whether or not the fat is desirable or undesirable. Intramuscular fat (IMF) is desirable for optimum organoleptic properties whereas, the fat in other depots must be at a minimum for optimum cutability. The deposition of fat in the meat animals is the result of two processes: adipogenesis (the absorption or synthesis of fatty acids from dietary origin and then transported to the adipose tissue), and the de novo fatty acids synthesis (DFS) from precursors (e.g., glucose, lactate) directly in the adipocytes [1].

IMF or marbling plays a critical role in meat eating quality, because of its great impacts on tenderness, juiciness and flavor of the meat [2–4]. Previous studies reported that preference for the IMF degree in pork varies widely among countries; about 47% of surveyed Korean consumers showed a strong preference for marbled pork, followed by Taiwan (34%), Japan (32%), China (23%) and Mexico (21%) [5]. According to a consumer evaluation study by Papanagiotou et al. [6]: marbling is the most important determinant of pork purchasing decision by Greece consumers. Ngapo [7] surveyed some Canadian provinces and showed a significant proportion of consumers strongly prefers marbled pork. A study reported by Argemí-Armengol et al. [8] showed that more than a half of Spanish and Portugal consumers (n–= 974) strongly prefer highly marbled pork. In general, these consumer studies have emphasized the importance of IMF in pork eating quality.

Korean native black pig (KNP), as an indigenous porcine breed, was present on the Korean Peninsula thousands of years ago [9]. The KNP, generally maintained in a small population, is characterized by a uniform black coat color and strong disease tolerance [10]. Due to its superior meat quality (hard and white-colored fat, and high marbling) and outstanding palatability, the KNP has become the most popular domestic pig breed today [11,12]. In recent years, there is a high demand for meat from the KNP, despite its price being much more expensive than meat from other commercial pig breeds [13]. However, KNP exhibits low growth performance and lean rate compared to the Western-originated commercial pig breeds, so this indigenous breed has been used as a highly valuable genetic resource for crossbreeding with the Western breeds (e.g., Landrace and Yorkshire) to generate crossbred pigs with a higher growth rate, leanness and meat quality [10,14]. Most recently, the National Institute of Animal Science (NIAS, Korea) has developed a novel porcine breed (Woori-heukdon [WHD]) through the crossbreeding of Duroc sows and KNP sires [15]. In 2015, the WHD was registered in the Food and Agriculture Organization Domestic Animal Diversity-Information System, and they have recently been introduced for commercial meat production in the country. However, we have recently observed that the use of available commercial diets resulted in an excessive fat deposition in WHD carcasses compared with other commercial pig breeds [16]. Also, the IMF content in WHD meat is still lower compared to that in meat from other indigenous breeds such as Iberian pigs [17].

Recently, researchers have proposed that dietary amino acids (e.g., valine, tryptophan, lysine, histidine, isoleucine, leucine, phenylalanine and threonine) supplementation could be an effective intervention in reducing body fat deposition and improving the IMF in pork [18,19]. The mechanisms underlying this phenomenon is that the supplied amino acids could alter the functional role of key lipid metabolism- related factors (e.g., peroxisome proliferator activated receptor gamma and sterol regulatory element-binding protein-1 etc.) [20]. On the other hand, chromium is a trace element that is naturally present in a variety of foods such as meat, fish, fruits, drinks and grains [21]. Chromium is known as a glucose tolerance, it amplifies the insulin-like growth factors, which reduces the conversion of glucose to adipose tissue [22,23]. The National Research Council [24] has noted that chromium should be considered as a key ingredient in livestock nutritional supplementation. A number of studies have shown that dietary supplementation with 200–400 μ/kg chromium reduces fat accretion in pork carcasses [25].

To the best of our knowledge, however, no studies were conducted to investigate the effects of combined dietary supplementation with amino acids and chromium on the carcass traits, meat yield and quality of commercial pig breeds in general and WHD pigs in particular. To reduce the excessive fat accretion and increase the IMF content in WHD, we have developed particular feeding diets (supplemented with additional 4%, 8% and 12% of lysine, isoleucine, methionine, threonine, valine and tryptophan, and different doses of chromium), and our preliminary results revealed that the dietary supplementation of additional 4% of these amino acids and 0.1% chromium effectively reduced the quantity of belly fat in growing-WHD pigs (below 60 kg body weight, data not shown). Hence, this study aimed to assess the effects of supplementation with additional 4% lysine, methionine, isoleucine, threonine, valine and tryptophan) and 0.1% chromium picolinate on the meat yield and quality properties of finishing WHD pigs.

MATERIALS AND METHODS

Animals and feeding treatment

The experimental protocols used in this study were reviewed and approved by the Institutional Animal Care and Use Committee of NIAS (NIAS-2020-437). The experiment was performed between January and July 2023 at the Swine Experimental Farm (Cheonan) and Animal Products Utilization Division (Wanju) of NIAS (Korea). A total of 40 WHD piglets (Duroc sow [62.5%] × KNP sire [37.55%]) at same weaning age (21 days of age and body weight: 31.49 ± 0.24 kg) were randomly divided into two feeding groups. Each group had 20 pigs concluding 10 castrated males and 10 females. All pigs of the control group were fed basal diets that were formulated to meet National Research Council [26] nutrient requirements. The pigs of experimental group were received a basal diet + 4% additional supplementation of lysine, isoleucine, methionine, threonine, valine and tryptophan during the growing phase (30–65 kg body weight), and basal diet + 0.1% (w/w) chromium picolinate during the finishing phase (65–110 kg body weight). The chemical ingredients of the feeding diets at the growing and finishing phases are presented in Table 1. The dose of supplemented amino acids and chromium were based on results of our preliminary study (data not shown) and previous studies [19,27,28]. During the experiment, the animals were housed in different cages (3.5 × 5.0 m, 0.8m^2/head) and freely accessed to the feed and water. The pigs were harvested when they reached a common market weight (approximately 180 days-old and 110 kg body weight).

Slaughter and carcass composition measurement

At the end of the feeding trial, the pigs were transported from the experimental farm to a slaughter house with a transporting duration of approximately 2 h. At the abattoir, the pigs were laired in cages for 3 h with full access to water. Slaughter was performed following the commercial process. After removal of internal organs, head, feet and tail, the carcasses were split down the midline, washed using high-pressure washing pumps, and chilled at 2℃. During the slaughter, the live and carcass weights were recorded using a scale installed on the production line.

After 24 h of slaughter, back-fat thickness was measured using a caliper on the midline between 11th and 12th rib, and last rib and first lumber vertebra. Next, both sides of each carcass were dissected into three portions (picnic shoulder, mid-section containing loin and belly, and ham) which were then dissected into 7 cuts (loin, shoulder ribs, shoulder butt, tenderloin, belly, picnic and ham), following the instruction of the Korean Pork Cutting Specification (KPCS) [29]. Thereafter, each cut was manually separated into skin, fat, bone and muscle.

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Table 1. Chemical composition of feeding diets[1)]

Items	Growing phase		Growing-finishing phase	
	CD[2)]	ED	CD	ED
Ingredient (%)	100.00	100.00	100.00	100.00
Corn (yellow dent)	64.17	63.93	69.00	68.90
Soybean meal (solvent extracted)	19.10	19.10	10.80	10.80
Wheat (soft red)	8.00	8.00	15.00	15.00
Molasses (sugarcane)	3.00	3.00	2.00	2.00
Beef tallow	2.00	2.00	0.10	0.10
Calcium phosphate (dicalcium)	1.20	1.20	0.75	0.75
L-Lysine-HCl	0.61	0.68	0.57	0.57
L-Threonine	0.13	0.16	0.11	0.11
DL-Methionine	0.10	0.13	0.02	0.02
L-Isoleucine	-	0.02	-	-
L-Tryptophan	0.18	0.24	0.20	0.20
L-Valine	0.08	0.11	0.03	0.03
Limestone (groundc)	0.73	0.73	0.72	0.72
Sodium chloride	0.30	0.30	0.30	0.30
Vit min mix	0.30	0.30	0.30	0.30
Phytase	0.05	0.05	0.05	0.05
Choline	0.05	0.05	0.05	0.05
Chromium picolinate	-	-	0.00	0.10
Metabolic energy (kcal/kg)	3,304	3,308	3,313	3,309
Crude protein (%)	15.49	15.66	12.98	12.97

[1)]The amino acids level in the feeding diets was made based on the Standardized Ileal Digestability (SID) (NRC [26]).

[2)]CD (control diet), a basal diet; ED (experiment diet), a basal diet + 4% lysine, isoleucine, methionine, threonine, valine and tryptophan during growing phase, and a basal diet supplemented with 0.1% chromium picolinate during finishing phase.

Meat quality assessment

For meat quality properties analysis, three representative cuts: loin (m. *longissimus thoracic et lumborum* [LTL]), belly and ham (m. *semimembranosus*) collected from the left carcass sides were used. The cuts were then prepared into sub-samples, and the sampling manners were fixed for all the cuts in each analysis.

pH was measured in triplicate using a pH meter (pH*K 21, NWK-Technology GmbH, Aichach, Germany). Before use, the device was calibrated with provided standard solutions (pH 4.00 and pH 7.00) following the manufacturer's instruction.

The meat color was measured after 30 min blooming at 5 different locations on the surface of each sample, using a color meter (CR-400, Minolta Camera, Osaka, Japan). The color meter was calibrated against a standard white tile (Y = 86.5, X = 0.3171 and y = 0.3331). The color parameters measured were CIE L*, a* and b*. Cooking loss and shear force value were measured using the procedures as described in our previous study [16].

The chemical composition (protein, fat, moisture and collagen) was determined with a Food Scan™ Lab 78810 (Foss Tecator , Hilleroed, Denmark) as described by Anderson et al. [30].

Fatty acid composition

The fatty acids content was analyzed following the method of Folch et al. [31]. Briefly, lipid content in the pork sample (10 g each) was extracted with chloroform: methanol (2.1, v/v). Following

adding with 20 g of Na_2SO_4 and vortexing for 1 min, the lipid layer was carefully collected and placed in Erlenmeyer flask which was concentrated using rotary evaporator in pre-heated 55℃ water bath. Thereafter, 1 mL tricosanoic acid and 1 mL of 0.5N NaOH were added to each the sample, thoroughly mixed and placed into vials. A gas chromatography (GC)/flame ionization detector (FID; Varian Technologies, Palo Alto, CA, USA) was used for analyzing the fatty acids. The GC/FID conditions set was same as those shown in our previous study [16].

Flavor volatile compounds

To assess whether the dietary supplementation affected the flavor properties, two representative cut types (loin and belly) were used. The analysis of flavor volatile compounds was done following the procedure of Van BA et al. [32] with suitable modifications. The pork samples were manually chopped and cooked at around 180℃ on a frying-pan with continuously turning for about 2 min. Afterward, the samples (2 g each) were taken, placed into 20-mL vial and tightly capped with magnetic cap. Extraction of volatiles was carried out at 60℃ for 50 min using a SPME auto-sampler (PAL RSI 85, Agilent, Santa Clara, CA, USA), and were then analyzed using a GC and mass spectrophotometry (5977B MS, Agilent) under the conditions as described by Hoa et al. [16]. All flavor volatiles were identified by using Wiley library (Agilent) and further confirmed by external standards. The concentration of identified compounds was calculated using a concentration-known internal standard (2-methyl-3-heptanone).

Statistical analysis

Data was analyzed using the Statistical Analysis System (SAS) Enterprise software (version 7.1, SAS Institute, Cary, NC, USA). The General Linear Model procedure of the SAS was used in which the feeding diet was set as the main effect while, the carcass traits, meat yield, color traits, chemical composition, shear force, fatty acids and flavor volatiles were set as random variables. Means comparison was carried out using the Duncan's test, and a p-value of < 0.05 was considered as statistically significant difference.

RESULTS AND DISCUSSION

Carcass and meat yield

Table 1 shows that no differences in the carcass traits were observed between the animal groups ($p > 0.05$). However, it was observed that the back-fat thickness tended to decrease in the pigs which were received the dietary supplementations. Compared to market weight of commercial pig breeds such as ([Landrace × Yorkshire] ♀ × Duroc ♂) finished at the same age (180 days old) reported by Van Ba et al. [33], the WHD pigs in the present study exhibited a similar body weight. This signifies that the growth potential of WHD pigs in this study was comparable to that of the commercial pig breeds. Furthermore, the results indicating no differences in the live weight between the pig groups could be related to the same dietary energy levels (3,300 kcal/kg). Regarding this, a numerous studies have also reported that feeding diets have no effects on pig's growth rate as they meet the required energy for growth [34–36].

Regarding the carcass composition, no effects of the dietary supplementations were observed on the total meat, fat, bone and skin weights ($p > 0.05$). This indicated a similar rate of protein and fat (subcutaneous and intermuscular fat depots) deposition in both the control and experimental groups. Similar to the present results, Hu et al. [19] found no effects of dietary amino acids supplementation on the total meat, fat, bone and skin yields of commercial pigs finished at 110–120 kg body weight. A study reported by Park et al. [28] showed a reduction in back-fat thickness and

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increased meat yield of pigs supplemented with 200 ppb chromium.

Chemical composition of meat

The chemical composition of WHD meat fed the control and experimental diets are presented in Table 2. IMF content is recognized to be the most important constituent determining eating quality of meat because it contributes to tenderness, juiciness and flavor [3,4]. Therefore, producing pork with increased IMF content to meet the consumer's demand is critical task for the pig industry [19]. Results showed that the pigs received the dietary supplementation had a significantly higher IMF content in both loin (increased by 1.55%) and ham (increased by 0.94%) than the control group ($p < 0.05$). The representative images showing the transverse cuts of loins are shown in Fig. 1. Our results align with those of Ma et al. [18] and Hu et al. [19], who reported an increase in IMF content of pork LTL muscle fed dietary amino acids (arginine and glutamic acid) supplementation. Tan et al. [37] also found an approximately 70% greater IMF content of *longissimus dorsi* (LD) muscles of growing-finishing pigs received dietary amino acids supplementation compared to non-supplemented pigs. In contrast to the increase of IMF in the loin and ham cuts, a significant decrease (by approximately 7%) of fat content was observed in the belly cut of pigs fed the experimental diet (41.05%) compared to the control diet (47.48%). In the present study, the belly cuts were fabricated according to the KPCS [29], where only the skin and ribs are removed. Therefore, the fat content, is comprised of all subcutaneous, intermuscular and IMF depots. This signifies that supplementation with the amino acids and chromium picolinate effectively reduced the subcutaneous and/or intermuscular fat deposition on the belly cut. We have recently observed that the belly cut of WHD pigs has a much higher fat content (over 40%) compared to that of commercial LYD pig (around 30%) [16]. Such the high fat content may result in a higher trimming loss and reduced consumer preference for the belly. In the present study, the dietary supplementations with amino acids and chromium effectively increased the desirable fat (IMF) in the lean cuts (loin and ham) and decreased the undesirable fat (e.g., subcutaneous and/or intermuscular fat) in the high-fat content cut like belly.

Table 2. Proximate composition of WHD meat by feeding diets

Cut	Composition	CD[1)]	ED
Loin	Fat (%)	4.49 ± 1.96[b]	6.04 ± 3.05[a]
	Moisture (%)	71.94 ± 1.24	71.06 ± 1.91
	Protein (%)	22.15 ± 1.09[a]	21.22 ± 1.68[b]
	Collagen (%)	0.26 ± 0.05	0.28 ± 0.04
Ham	Fat (%)	2.40 ± 1.00[b]	3.34 ± 1.70[a]
	Moisture (%)	74.15 ± 0.99	73.72 ± 1.43
	Protein (%)	21.98 ± 0.78[a]	21.19 ± 1.15[b]
	Collagen (%)	0.24 ± 0.04	0.24 ± 0.04
Belly	Fat (%)	47.48 ± 7.84[a]	41.05 ± 6.71[b]
	Moisture (%)	43.68 ± 5.80[b]	47.67 ± 5.36[a]
	Protein (%)	10.80 ± 1.55	11.03 ± 2.09
	Collagen (%)	1.58 ± 0.33	1.30 ± 0.36

[1)]CD (control diet), pigs were fed a basal diet; ED (experiment diet), pigs were fed a basal diet + 4% lysine, isoleucine, methionine, threonine, valine and tryptophan during growing phase and supplemented with 0.1% chromium picolinate during finishing phase.

[a,b]Means within a row with different superscripts are significantly different ($p < 0.05$).

WHD, Woori heukdon.

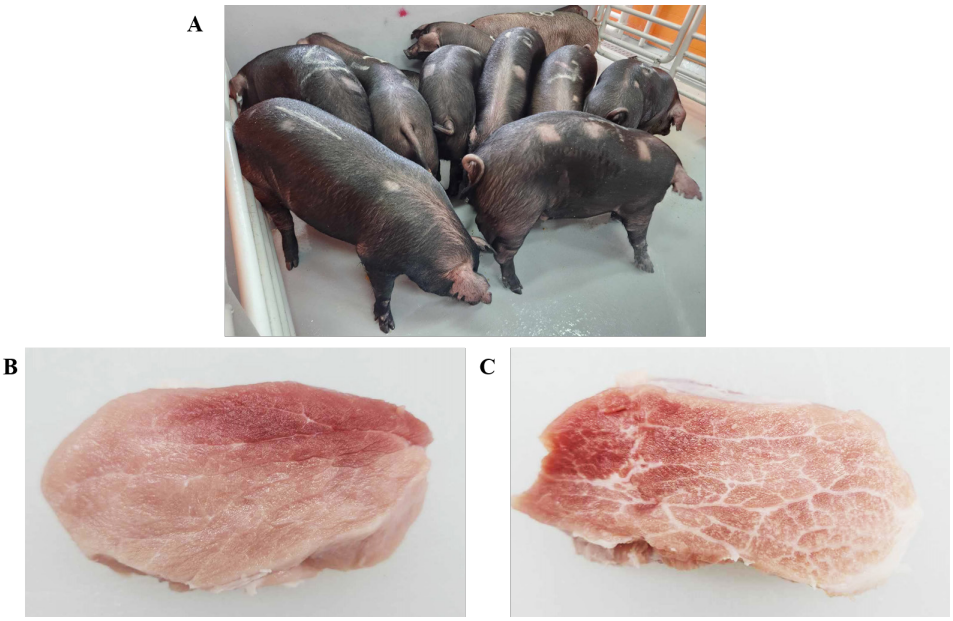

Fig. 1. Representative images show. (A) Finishing-Woori heukdon (WHD) pigs fed the dietary supplementation before slaughter, (B) cross-sectioned loin of non-supplemented WHD pigs, and (C) cross-sectioned loin of supplemented WHD pigs.

The adipose tissues of pork carcass may be deposited from (i), diet-derived fatty acids and (ii), the DFS pathway [38]. In the DFS pathway, the fatty acids are synthesized by converting glucose into triglycerides through the glycolysis cycle [1]. The possible mechanisms underlying the phenomena observed in the present study could be due to: (i) the supplemented amino acids promoted the lipogenesis gene's expression in the muscle tissues [19], resulting in the increased IMF content, and (ii) the chromium could amplify the insulin action, resulting in increased glucose converting into energy required for pig's metabolic activities rather than for the DFS process [23]. Mooney and Cromwell [25] found a significant reduction in total carcass fat in growing-finishing pigs supplemented chromium picolinate or chromium chloride. In the present study, the dietary supplementations with combined amino acids and chromium did not affect the total carcass fat (Table 3), but it effectively decreased in the fat level of belly cut. This could be related to the synergetic effect of both the supplemented amino acids and chromium picolinate.

For the other composition, the dietary supplementations did not affect the moisture content but it reduced the protein content of loin and ham cuts, this was probably due to the increased IMF content in these cuts. The supplementations also caused an increase in the moisture content of belly, this could be associated with the decreased fat level in this cut, because the fat and moisture content in meat content are inversely related to each other [39].

Meat quality and color traits

It is well recognized that cooking loss (reflecting the water holding capacity), pH and shear force, are important quality traits of meat. The dietary supplementations did not affect on all these traits in the loin and belly cuts (Table 4) ($p > 0.05$). However, compared with the control group, the dietary supplementations reduced the cooking loss of belly ($p < 0.05$). This indicates that the dietary supplementations improved the water holding capacity of belly cuts. Color is an important quality trait of meat [40]. The dietary supplementations did not influence the lightness, redness and yellowness of all the three cuts examined (Table 5). Similar to the present fining, Tan et al. [37] and

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Table 3. Carcass traits and meat yield of Woori heukdon by feeding diets

Items	CD[1)]	ED
Slaughter weight (kg)	109.30 ± 3.20	109.60 ± 2.00
Hot carcass weight (kg)	85.68 ± 1.96	85.40 ± 2.11
Cold carcass weight (kg)	83.80 ± 4.88	83.40 ± 5.67
Back-fat thickness (mm)	28.78 ± 0.54	27.75 ± 0.66
Trimable fat (kg)	17.50 ± 0.12	16.69 ± 0.10
Bone (kg)	8.49 ± 0.68	8.43 ± 0.57
Skin (kg)	6.31 ± 0.12	6.34 ± 0.13
Meat yield (kg)		
Tenderloin	1.09 ± 0.27	1.01 ± 0.20
Loin	7.16 ± 0.54	7.12 ± 0.48
Shoulder butt	4.46 ± 1.16	4.36 ± 1.33
Picnic	9.61 ± 0.83	9.35 ± 0.77
Ham	15.64 ± 0.29	15.36 ± 0.21
Belly	13.28 ± 2.54	13.25 ± 2.19
Rib	2.52 ± 0.41	2.35 ± 0.42
Total meat yield	53.76 ± 0.53	52.80 ± 0.58

[1)]CD (control diet), pigs were fed a basal diet; ED (experiment diet), pigs were fed a basal diet + 4% lysine, isoleucine, methionine, threonine, valine and tryptophan during growing phase and supplemented with 0.1% chromium picolinate during finishing phase.

Table 4. Meat quality traits WHD meat by feeding diets

Cut	Cooking loss (%)		pH		Shear force (kgf)	
	CD[1)]	ED	CD	ED	CD	ED
Loin	24.06 ± 6.33	22.18 ± 4.14	5.57 ± 0.07	5.56 ± 0.07	2.07 ± 0.13	2.14 ± 0.11
Ham	27.57 ± 3.26	27.23 ± 17.50	5.65 ± 0.09	5.68 ± 0.14	3.41 ± 0.37	3.86 ± 0.21
Belly	9.33 ± 1.86[a]	7.16 ± 1.93[b]	6.21 ± 0.14	6.20 ± 0.15	NM	NM

[1)]CD (control diet), pigs were fed a basal diet; ED (experiment diet), pigs were fed a basal diet + 4% lysine, isoleucine, methionine, threonine, valine and tryptophan during growing phase and supplemented with 0.1% chromium picolinate during finishing phase.

[a,b]Means within a row with different superscripts are significantly different ($p < 0.05$).

WHD, Woori heukdon; NM, not measured.

Table 5. Color traits of WHD meat by feeding diets

Cut	L* (Lightness)		a* (redness)		b* (Yellowness)	
	CD	ED	CD	ED	CD	ED
Loin	54.81 ± 3.66	54.61 ± 4.37	7.98 ± 1.58	7.82 ± 1.59	4.81 ± 1.61	4.02 ± 1.32
Ham	49.17 ± 2.51	48.82 ± 2.85	11.53 ± 1.22	11.95 ± 1.36	4.37 ± 1.08	4.37 ± 0.96
Belly	46.61 ± 2.99	45.58 ± 3.39	16.28 ± 1.57	16.24 ± 1.66	5.12 ± 0.88	5.31 ± 1.45

CD (control diet), pigs were fed a basal diet; ED (experiment diet), pigs were fed a basal diet + 4% lysine, isoleucine, methionine, threonine, valine and tryptophan during growing phase and supplemented with 0.1% chromium picolinate during finishing phase.

WHD, Woori heukdon.

Hu et al. [19] reported no effects of dietary supplementations with amino acids (e.g., arginine and glutamic acid) on pH, cooking loss and color traits of pork LD muscles. Until now, there is limited research on the dietary supplementation with chromium on pork quality. Studies by Boleman et al. [41] and Wang et al. [42] also showed that dietary supplementation with chromium chloride or

Table 6. Fatty acid profiles of WHD meat by feeding diets

Items	Loin		Belly	
	CD	ED	CD	ED
C14:0	1.50 ± 0.23	1.50 ± 0.18	1.42 ± 0.19	1.48 ± 0.22
C16:0	31.40 ± 1.87	31.11 ± 1.50	30.23 ± 1.64	30.30 ± 1.58
C16:1n7	2.65 ± 1.00	3.05 ± 0.56	2.11 ± 0.43	2.41 ± 0.49
C18:0	14.62 ± 1.54[b]	16.11 ± 1.29[a]	14.49 ± 1.44[b]	15.64 ± 1.08[a]
C18:1n9	42.20 ± 2.19	41.91 ± 1.68	42.70 ± 2.53	41.80 ± 1.27
C18:1n7	0.12 ± 0.03	0.12 ± 0.03	0.11 ± 0.02	0.12 ± 0.02
C18:2n6	6.36 ± 2.25[a]	5.04 ± 1.06[b]	7.73 ± 0.91	7.04 ± 1.59
C18:3n6	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00
C18:3n3	0.23 ± 0.11[a]	0.15 ± 0.06[b]	0.27 ± 0.07	0.24 ± 0.09
C20:1n9	0.67 ± 0.16	0.74 ± 0.07	0.73 ± 0.08	0.75 ± 0.11
C20:4n6	0.19 ± 0.06	0.20 ± 0.07	0.15 ± 0.05	0.16 ± 0.03
C22:4n6	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.01
SFA	47.52 ± 3.18	48.72 ± 1.90	46.13 ± 2.85	47.42 ± 2.03
UFA	52.48 ± 3.18	51.28 ± 1.90	53.87 ± 2.85	52.58 ± 2.03
MUFA	45.63 ± 2.86	45.82 ± 1.53	45.66 ± 2.63	45.09 ± 1.29
PUFA	6.85 ± 2.37[a]	5.46 ± 1.09b	8.21 ± 0.98	7.49 ± 1.67
n3	0.23 ± 0.11[a]	0.15 ± 0.06b	0.27 ± 0.07	0.24 ± 0.09
n6	6.62 ± 2.28[a]	5.30 ± 1.05b	7.94 ± 0.95	7.25 ± 1.60
n6/n3	30.93 ± 7.24	40.76 ± 2.44	31.67 ± 1.76	33.08 ± 1.55
MUFA/SFA	0.97 ± 0.13	0.94 ± 0.07	1.00 ± 0.12	0.95 ± 0.06
PUFA/SFA	0.15 ± 0.06[a]	0.11 ± 0.03[b]	0.18 ± 0.03	0.16 ± 0.04

CD (control diet), pigs were fed a basal diet; ED (experiment diet), pigs were fed a basal diet + 4% lysine, isoleucine, methionine, threonine, valine and tryptophan during growing phase and supplemented with 0.1% chromium picolinate during finishing phase.a,bMeans within a row with different superscripts are significantly different ($p < 0.05$).
WHD, Woori heukdon; SFA, saturated fatty acid; UFA, unsaturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

picolinate did not influence the meat quality of LD muscles of finishing pigs.

Fatty acid profiles

To examine whether the dietary supplementations influence the fatty acids composition of meat, two representative cuts (loin and belly) were used, and the results are shown in Table 6. For the loin cut, the dietary supplementations only affected the C18:0, C18:2n6 and C18:3n3 contents. Compared with the experimental diet, the pigs fed the control diet had a lower C18:0 content, and higher C18:2n6 and C18:3n3 contents, which contributed to the higher total polyunsaturated fatty acids (PUFA), n3 and n6 PUFA contents in this cut ($p < 0.05$). For the belly cut, only C18:0 content was affected by the dietary supplementations. Oleic acid (C18:1n9) is well recognized as the most predominant and important for cooked meat flavor development [43]. We observed that the dietary supplementations did not alter the C18:1n9 content in both the cuts. However, under the current experimental conditions, the alternation of C18:0, C18:2n6 and C18:3n3 contents might be related to the supplemented amino acids or chromium alone and their combined effects on the absorbing rate of these fatty acids from the feeding diets and/or activity amplification of fatty acid synthase that converts malonyl-CoA to palmitate and subsequently elongated to C18:0 by elongase enzyme in the de novo fatty acid synthesis pathway [1]. Also, the results indicating the decreased PUFA content of loin in the dietary supplementation group could be related to the decreased desaturation of saturated fatty acids (SFAs) into unsaturated fatty acids (UFAs) by the

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desaturase enzymes in the DFS pathway. Another possible mechanism responsible for the change of fatty acids composition by the dietary amino acids supplementation is the increased production of nitric oxide from these amino acids, which reduces the uptake of glucose by stimulating glucose-oxidation in muscle tissues, and subsequently reduces the DFS [37]. In general, it was observed that dietary supplementations apparently showed a negligible effect on the fatty acids compositions of the pork. In agreement with our results, numerous studies have also found that dietary amino acids or 200 ppm chromium picolinate supplementation do not alter total SFA and UFA contents in LD muscles of growing-finishing pigs [19,44].

Flavor volatile composition

The concentration of aroma volatiles of cooked loin and belly samples are presented in Table 7. It is well recognized that aroma flavor sensed by smell buds is a very important eating quality trait [45,46]. The aroma flavor of meat is composed of a variety of volatiles which are generated as a result of thermal oxidation of lipids, Maillard reaction, and the interaction between lipid-thermally oxidized products with the products of Maillard reaction [45,47]. Under the current analytic conditions, a total of forty-four aroma volatiles included: 18 aldehydes, 8 alcohols, 3 ketones, 4 sulfur-and nitrogen-containing compounds, 5 pyrazines and 5 hydrocarbons, were detected from the loin and belly cuts. We observed that the dietary supplementations showed a greater effect on the aroma volatiles composition of loins rather than on those of the belly cut. With regards to aldehydes, the concentration of 4 aldehydes (hexanal, heptanal, E,2-hetenal and E,E,2,4-decadienal) as well as total aldehydes content in the loins were significantly influenced by the feeding diets while, only an aldehyde (benzaldehyde) in belly cut was affected. Aldehydes are mainly produced from the thermal oxidation of UFAs [48,49], and some of them are produced from the Maillard reaction [46]. Hexanal, heptanal and E,2-heptenal, are known to be the oxidation products of C18:2n6 [49]. These aldehydes, with a low odor detection threshold (0.003–0.005 ppm) and associated with green, grassy and harsh odors, are considered as the unpleasant compounds in cooked meat [47]. Interestingly, compared with the control group, the dietary supplementations decreased (p–< 0.05) the concentrations of these unpleasant aldehydes. This phenomenon may be explained by the decrease of PUFAs (e.g., C18:2n6) content of the meat (in case of loin cut) as the result of the dietary supplementations (Table 5). Similar to the current findings, Elmore et al. [50] stated that a small change in fatty acids of meat could result in an alteration in aroma volatiles of cooked meat. For the oleic acid-derived aldehydes (e.g., octanal, nonanal and decanal) associated with desirable odors (e.g., fatty note), no effects of the dietary supplementations were observed. This is probably because of the C18:1n9 content that was similar in both the control and supplementation groups (Table 5).

With regards to alcohols, the dietary supplementations did not affect this volatile class in the belly cut, and but reduced ($p < 0.05$) the amount of 1-pentanol, 1-heptanol and total alcohols content in the loin. Alcohols are formed as a result of the fatty acids oxidation, and are not important contributors of cooked meat flavor because of their high odor threshold (0.5–4 ppm) [4]. Therefore, the lower alcohols content in the loin of pigs received the dietary supplementation could be related to its lower PUFAs (e.g., C18:2n6 and C18:3n3) content compared to the control group (Table 5).

Sulfur-and nitrogen-containing compounds, and pyrazines, as the Maillard reaction-derived products with desirable odor notes (meaty and roasty odor notes), are the most important contributors of cooked meat flavor [45,51]. Interestingly, the dietary supplementations led to an increase of total sulfur-and nitrogen-containing compounds as well as pyrazines content in both the cuts. The increases of sulfur-and nitrogen-containing compounds as well as pyrazines contents

Table 7. Concentration (μg/g) of aroma volatile compounds of WHD meat by feeding diets

Compounds	Retention time (min)	Loin		Belly		IM[1)]
		CD[2)]	ED	CD	ED	
Aldehydes						
2-Methyl pentanal	1.611	0.013 ± 0.005	0.010 ± 0.005	0.031 ± 0.003	0.043 ± 0.002	MS + STD
2-Methyl propanal	1.867	0.004 ± 0.000	0.003 ± 0.000	0.003 ± 0.000	0.003 ± 0.000	MS + STD
Butanal	1.994	0.001 ± 0.000	ND	0.002 ± 0.000	0.002 ± 0.000	MS + STD
3-Methyl butanal	2.435	0.009 ± 0.000	0.007 ± 0.000	0.005 ± 0.000	0.010 ± 0.002	MS + STD
2-Methyl butanal	2.610	0.010 ± 0.001	0.007 ± 0.000	0.004 ± 0.000	0.007 ± 0.000	MS + STD
Petanal	3.036	0.041 ± 0.004	0.018 ± 0.001	0.180 ± 0.012	0.199 ± 0.093	MS + STD
Hexanal	5.654	0.673 ± 0.093[a]	0.127 ± 0.012[b]	2.381 ± 0.231	2.745 ± 0.265	MS + STD
Heptanal	8.808	0.043 ± 0.005[a]	0.017 ± 0.009[b]	0.112 ± 0.002	0.118 ± 0.004	MS + STD
E,2-Heptenal	10.291	0.002 ± 0.000[a]	0.0001 ± 0.000[b]	0.016 ± 0.003	0.017 ± 0.001	MS + STD
Benzaldehyde	10.375	0.014 ± 0.006	0.013 ± 0.001	0.035 ± 0.003[b]	0.052 ± 0.001[a]	MS + STD
E,E-2,4-Decadienal	11.136	0.024 ± 0.003[a]	0.007 ± 0.000[b]	0.077 ± 0.007	0.099 ± 0.004	MS + STD
Benzeneacetaldehyde	12.405	0.002 ± 0.000	0.003 ± 0.000	0.003 ± 0.000	0.003 ± 0.000	MS + STD
E,2-Octenal	12.728	0.002 ± 0.000	0.001 ± 0.000	0.012 ± 0.009	0.014 ± 0.008	MS + STD
Nonanal	13.712	0.038 ± 0.003	0.022 ± 0.009	0.078 ± 0.004	0.085 ± 0.003	MS + STD
E,2-Nonenal	14.834	0.003 ± 0.000	0.004 ± 0.000	0.005 ± 0.000	0.007 ± 0.000	MS + STD
Decanal	15.720	0.002 ± 0.000	0.002 ± 0.000	0.001 ± 0.000	0.001 ± 0.000	MS + STD
E,E-2,4-Nonadienal	15.872	0.001 ± 0.000	0.001 ± 0.000	ND	ND	MS + STD
E,2-Dodecenal	16.757	0.001 ± 0.000	0.001 ± 0.000	0.004 ± 0.000	0.004 ± 0.000	MS + STD
2-Undecenal	18.527	0.001 ± 0.000	0.001 ± 0.000	0.002 ± 0.001	0.002 ± 0.000	MS + STD
Total aldehydes		0.882 ± 0.086[a]	0.242 ± 0.001[b]	2.944 ± 0.139	3.409 ± 0.149	
Alcohols						
1-Penten-3-ol	2.839	0.001 ± 0.000	0.003 ± 0.000	0.006 ± 0.000	0.003 ± 0.001	MS + STD
1-Pentanol	4.601	0.026 ± 0.005[a]	0.005 ± 0.001[b]	0.140 ± 0.005	0.130 ± 0.004	MS + STD
1-Hexanol	7.905	0.006 ± 0.000	0.003 ± 0.000	0.048 ± 0.008	0.014 ± 0.006	MS + STD
1-Hexen-3-ol	8.083	ND	0.001 ± 0.000	0.003 ± 0.000	0.003 ± 0.000	MS + STD
1-Heptanol	10.668	0.008 ± 0.000[a]	0.003 ± 0.000[b]	0.018 ± 0.001	0.018 ± 0.001	MS + STD
1-Octen-3-ol	10.892	0.012 ± 0.001	0.003 ± 0.000	0.034 ± 0.003	0.030 ± 0.001	MS + STD
2-Ehyl-1-hexanol	12.072	0.004 ± 0.001	0.003 ± 0.000	0.008 ± 0.001	0.011 ± 0.001	MS
1-Octanol	13.004	0.004 ± 0.000	0.003 ± 0.000	0.009 ± 0.000	0.007 ± 0.001	MS + STD
Total alcohols		0.060 ± 0.003[a]	0.022 ± 0.003[b]	0.263 ± 0.020	0.214 ± 0.005	
Ketones						
2,3-Butanedione	1.940	0.001 ± 0.000	0.001 ± 0.000	ND	0.003 ± 0.000	MS + STD
2-Butanone	2.027	0.004 ± 0.000	0.003 ± 0.001	0.010 ± 0.001	0.009 ± 0.001	MS + STD
2-Heptanone	8.507	0.009 ± 0.001	0.006 ± 0.000	0.017 ± 0.001	0.014 ± 0.005	MS + STD
Total ketones		0.013 ± 0.006	0.010 ± 0.005	0.027 ± 0.007	0.024 ± 0.006	
Sulfur and nitrogen-containing compounds						
Carbon disulfide	1.754	ND	0.005 ± 0.000	ND	0.015 ± 0.001	MS + STD
Methional	8.912	0.001 ± 0.000[b]	0.004 ± 0.000[a]	ND	0.020 ± 0.005	MS + STD
Dimethyl trisulfide	10.570	0.008 ± 0.000	0.005 ± 0.000	0.004 ± 0.000	0.009 ± 0.000	MS + STD
2-Acethylthiazole	11.810	ND	0.006 ± 0.001	ND	0.009 ± 0.000	MS + STD
Total sulfur and nitrogen		0.006 ± 0.000[b]	0.020 ± 0.009[a]	0.005 ± 0.000[b]	0.055 ± 0.001[a]	
Pyrazines						
Methylpyrazine	6.377	0.003 ± 0.000	0.003 ± 0.001	0.001 ± 0.000[b]	0.015 ± 0.001[a]	MS + STD
2,5-Dimethylpyrazine	9.158	0.012 ± 0.001	0.012 ± 0.002	0.005 ± 0.001	0.025 ± 0.001	MS + STD
2-Ethyl-6-methylpyrazine	11.357	0.0005 ± 0.000[b]	0.001 ± 0.000[a]	0.003 ± 0.000	0.004 ± 0.001	MS
3-Ethyl-2,5-dimethylpyrazine	13.187	0.003 ± 0.000	0.004 ± 0.000	0.008 ± 0.002	0.008 ± 0.000	MS
2,5-Dimethyl-3-methylbutylpyrazine	17.717	0.001 ± 0.000	0.001 ± 0.002	ND	ND	MS
Total pyrazines		0.014 ± 0.002	0.020 ± 0.002	0.005 ± 0.001[b]	0.031 ± 0.004[a]	
Hydrocarbons						
Toluene	4.546	0.001 ± 0.000	0.001 ± 0.000	0.004 ± 0.000[a]	0.001 ± 0.000[b]	MS + STD
Ethylbenzene	7.574	0.001 ± 0.000	0.001 ± 0.000	0.002 ± 0.000	0.002 ± 0.000	MS + STD
1,3-Dimethylbenzene	7.815	0.006 ± 0.001	0.006 ± 0.001	0.008 ± 0.001	0.007 ± 0.001	MS
2,4,6-Dimethyldecane	11.368	0.001 ± 0.000	ND	0.006 ± 0.000	0.003 ± 0.000	MS
2,6,6-Trimethylheptane	12.517	0.002 ± 0.000	0.001 ± 0.001	0.002 ± 0.000	0.002 ± 0.000	MS
Total hydrocarbons		0.010 ± 0.005	0.008 ± 0.005	0.017 ± 0.009[a]	0.012 ± 0.004[b]	

[1)]IM, by MS from a library or STD.

[2)]CD (control diet): pigs were fed a basal diet; ED (experiment diet): pigs were fed a basal diet + 4% lysine, isoleucine, methionine, threonine, valine and tryptophan during growing phase and supplemented with 0.1% chromium picolinate during finishing phase.

[a,b]Means within a row with different superscripts are significantly different ($p < 0.05$).

WHD, Woori heukdon; MS, mass spectra; STD, external standards; ND, not detectable.

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in the cooked meat of pigs received the dietary supplementations may be related to the fact that: (i), higher availability of amino acids (from supplemented amino acids) in fresh meat, produced a higher amount of intermediated products (e.g., ammonia formed in the Strecker reaction during cooking) which interact with lipid-derived aldehydes in the later stages of Maillard reaction to yield these compounds [47], and (ii), the lower amount of unpleasant aldehydes (hexanal and heptanal produced from C18:2n6) elevated the formation of pyrazines, and sulfur-and nitrogen-containing compounds [49]. Regarding this, Elmore et al. [48] also noted that many of Maillard reaction-derived flavor volatiles are not formed or are formed at lower level when a higher PUFA content is present. Frank et al. [52] found that number and quantity of Maillard compounds (e.g., pyrazines) in meat increased with increasing IMF content. In the present study, the pigs received the dietary supplementations had a higher IMF content as aforementioned (Table 2).

Overall, although the WHD is known as a novel pig breed with a slow growth rate compared to the other commercial pig breeds [15], the slaughter weight of WHD pigs was similar to that of the commercial pig breeds when finished at a similar age [33]. As earlier mentioned, a significant proportion of worldwide consumers has a strong preference for highly-marbled pork [5], the marbling degree or IMF level, therefore, has become a major interest to the meat industry [1]. In the present study, WHD meat presented a considerably higher IMF content compared to that of other commercial breeds [19,53]. This suggests that WHD pig, with a good potential of growth and IMF accumulation, could be considered as an outstanding breed for production of high-quality meat to fulfil the consumer's preference. On the other hand, an excessive fat level may result in a more trimming loss and high risk of rejection by consumers [54]. In the present study, the dietary supplementation significantly reduced the fat deposition in the belly cut. This implies that dietary amino acids and chromium supplementation emerged as an effective nutritional intervention for improving IMF and lessening the undesirable fat (e.g., subcutaneous fat) deposition in pork carcasses.

CONCLUSION

In this study, the influences of combined dietary supplementations with amino acids and chromium on the carcass traits and composition, and meat quality of finishing WHD pigs were investigated. The dietary supplementations did not affect the live weight, carcass weight and total meat yield. As expected, the dietary supplementations considerably increased the IMF level of loin and ham cuts, and simultaneously reduced the fat content of belly cut. The dietary supplementations also did not cause any defect in quality such as pH, water holding capacity and color traits of the meat. Noticeably, the dietary supplementations significantly reduced the amount of PUFA-derived unpleasant aldehydes, and increased the number and quantity of Maillard reaction-derived aroma volatiles associated desirable odor notes (meaty and roasty odor notes). It may be said that the combined dietary supplementations with amino acids and chromium effectively improved the meat quality by increasing the IMF content, and producing more number and amount of pleasant aroma volatiles. Insights into the effects of dietary supplementation with amino acids and chromium on the tastes-related components and eating properties will be investigated in future study.

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