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Discriminating the quality of local pork from crossbred pork from extensive production of ethnic minorities in mountainous northern Vietnam

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Abstract

Developing short food supply chains for products from local pig (*Sus scrofa domesticus*) breeds may offer chances for smallholders in rural areas to participate in niche markets and obtain additional income. Because the authenticity and distinctness of products are crucial for establishing marketing, this study compared selected product characteristics of pork from the Vietnamese Ban breed with pork from crossbreds, each derived at their typical market weight and from their respective extensive and semi-extensive production environment; thus resembling the combination, the products are available for customers. Traditional Ban pork could be effectively discriminated from crossbred pork through cut dimensions, exemplified by the significantly reduced loin eye area ($P < 0.001$), and by the significantly reduced backfat thickness ($P < 0.001$). Also, marbling fat was significantly decreased in local pork ($P < 0.001$), whereas differences in further meat quality parameters were rather weakly expressed. The significantly higher share of polyunsaturated fatty acids in loins of traditionally produced Ban pigs ($P = 0.003$) could possibly result in a preferred nutritional value, but lower oxidative stability of the products. This study provides novel information to improve the marketing of specialty pork in Vietnam and comparable situations in the Southeast Asian Massif.

Keywords: fatty acid composition, meat quality, niche pork market, pig genetic resources, rural development, smallholder pig production

1 Introduction

The Southeast Asian Massif (SEAM) covers an area of 2,500,000 km^2 (north-eastern India, Southeast Asia and four Chinese provinces) and there are estimated to live approximately 100 million minority people (Scott, 2009). These societies are culturally and linguistically highly diverse, but they share a state of marginality and forms of subordination to the powerful lowland states (Michaud, 2010). Promoting market-oriented agriculture by cultivating a cash crop and/or intensifying staple crop production yielded some successes with respect to the economic development of marginalised smallholders. But, focusing on one main crop species may increase production risks and vulnerability due to climatic conditions, pests and the fall of market prices (Sturgeon *et al.*, 2013). Therefore, risk mitigation by diversification into a multiplicity of activities and income sources including handicraft, trading, services and animal production can represent essential livelihood strategies for the rural population of this area (World Bank, 2012).

In the SEAM, pig keeping is a widespread activity of rural households. For instance, in Vietnam pigs are kept by more than 80 % of rural households in the mountainous regions (Roland-Holst *et al.*, 2010). Thus, pork pro-

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duction could represent a chance for smallholders to participate in growing markets for animal-based products and diversify their incomes. However, the prospects for smallholders to commercialise pig production, specifically those located in the less accessible uplands remain limited because they are disadvantaged by an array of market-related barriers, preventing them from entering the commodity market. Therefore, smallholder pig husbandry in the SEAM is often still subsistence-oriented and based on extensively managed local breeds thriving on low-cost feeding (e.g., Riedel *et al.*, 2012). In the northern mountainous regions of Vietnam, the Ban breed (different names exist) is one of the most widely spread local breeds. Ban pigs are mainly black-coated with small erect ears, and have a low productive and reproductive potential, but are robust and adapted to harsh environments. Similar phenotypic characteristics have been reported for local pig populations in the uplands of south-western China (Riedel *et al.*, 2012), Laos (Phengsavanh *et al.*, 2010), and northern Thailand (Nakai, 2008). In contrast, where favourable market conditions prevail, the application of high-yielding exotic breeds in crossbreeding schemes could help to better match increasing consumer demand for lean pork. In fact, crossbreeding schemes have been adopted by smallholders in the lowlands and those close to provincial centres (e.g., Luc *et al.*, 2014).

Besides the demand for ‘regular’ lean meat, specific groups of urban consumers more recently expressed preferences for pork from local pigs reared without industrial feed (Lapar *et al.*, 2010). On special occasions, such as the Lunar New Year celebrations, the demand for local pork is at its highest, implying a cultural background for these preferences. Particularly pigs slaughtered at a body weight of less than 20 kg fetch high prices on the markets of southwest China (Neo & Chen, 2009) and northern Vietnam (Le *et al.*, 2016). The niche marketing of value added animal-based products has been identified as a development option for small-scale farmers, but for the smallholders of the SEAM creating marketing options for specialty pork represents a challenge. Information on the unique traits of traditional pork products and its markets is lacking, preventing effective value chain coordination and marketing. First reports demonstrate that target markets could be represented by specialty restaurants or ‘green’ food shops in the densely populated lowlands (Le *et al.*, 2016). However, consumers may not be willing to pay a premium price for pork products from local breeds unless they can rely on the authenticity of the product and its distinctness from commodity production (FAO, 2013).

The objective of this study was, therefore, to compare selected product characteristics and physico-chemical meat quality traits of traditionally produced pork derived from purebred Vietnamese Ban pigs with pork from crossbred pigs. Due to its storability, lean meat was considered more important for evaluation than edible body parts, internal organs and blood, which are also appropriate for consumption. The study aimed at providing information to improve marketing of specialty pork in northern Vietnam and comparable situations in the SEAM. Therefore, it was decided that the context of this study should reflect the product categories as available for consumers, that is, both genetic groups were raised by smallholder farmers on a management level adapted to the respective genetic resource (extensive for Ban and semi-extensive for crossbreds). Thus, production environments and marketing weights differed largely between genetic groups, however the age at slaughter, slaughter locations and procedures were standardised.

2 Materials and methods

Transport and slaughtering of live pigs (*Sus scrofa domesticus*) complied with all legal requirements imposed by the Socialist Republic of Vietnam. The trials were conducted under the supervision of the Veterinary Department of Son La province, Vietnam.

2.1 Study site

The study was carried out from December 2013 until February 2014 in the city of Son La and its surrounding districts. Son La is the capital of the same-named mountainous province in north-western Vietnam, located on the eastern flank of the SEAM. More than 70 % of the population of Son La province is represented by ethnic minorities, predominantly speaking Tai-Kadai or Miao-Yao languages (World Bank, 2009).

2.2 Animal selection

In total, 33 purebred Ban pigs and 12 crossbred pigs from Piétrain × Duroc sires (PiDu) were purchased from smallholder farms. The semi-extensively produced commercial crossbreds served as reference. A power analysis (level of significance set to 5 % and statistical power set to 80 %) for the most important meat quality traits indicated that numbers of approximately 10 heads per group were required. In that respect, trait variances for the calculation of effect sizes could be derived from literature, but mean differences were rather roughly estimated, because information on the meat quality of light-weight local pigs is lacking. Given a study on the effect of live weight at slaughter on the carcass quality of Ban pigs was carried out in parallel (Muth *et al.*, 2017), it was possible to expand the number of Ban pigs and so to reduce the amount of random sampling error. This improved the generation of benchmark data for local pork products in view of the high variability in husbandry conditions.

Farms were selected purposively based on the availability of suitable fatteners. All animals were castrated male pigs at an age of 6 to 7 months, each originating from a different litter, dam and farm (45 farms in total). For most of the PiDu-sired crossbreds, the dam line was represented by a local breed (e.g., Mong Cai), with a varying degree of genetic admixture with exotic breeds, which could, however, not be determined.

Information obtained from semi-structured questionnaires showed that compared to producers of crossbred pigs, the distance to the in- and output markets of Son La was longer for producers of traditional Ban pork (Table 1). Ban keepers also applied less diversified diets and used more fibrous feed components. All farmers cooked the diet before feeding. For diet preparation, farmers used on average 4.4 kg fresh matter pig $^{-1}$ day^{-1} for Ban fatteners and 5.1 kg fresh matter pig $^{-1}$ day^{-1} for PiDu-sired crossbreds. Husbandry conditions were more diverse for purebred Ban pigs, which were frequently semi-scavenging (i.e. confined only at night) or kept in spacious enclosures.

The confounding of genetic with environmental factors with respect to housing and feeding were accepted precisely because of their possible contribution to the final product configuration under real production conditions enabling a comparison of the raw products representative for the market. At slaughter, purebred Ban pigs were, on average, 6.4 months old (range: 6.1 to 6.9 months) and weighed 14.8 kg (range: 6.5 to

Table 1: *Characterisation of production systems in relation to the genetic background (purebred Ban pigs vs. crossbreds from Piétrain × Duroc (PiDu) sires) of products.*

Trait	*Purebred Ban pigs* N=33	*PiDu-sired crossbreds* N=12
Farm distance to regional market (km)	28.7 ± 14.3 (R: 4–45)	8.3 ± 6.5 (R: 0–25)
Number of fatteners kept (N)	4.7 ± 3.0 (R: 1–12)	8.0 ± 4.5 (R: 4–17)
Number of diet ingredients used (N)	2.9 ± 0.8 (R: 2–4)	4.1 ± 1.0 (R: 3–6)
Housing type (%)		
Penned	51.5	100.0
Enclosed	15.2	0.0
Semi-scavenging	33.2	0.0
Farmers using a feed item (%)		
Banana pseudostem	90.9	41.7
Rice bran	81.8	58.6
Vegetables (leaves)	39.4	58.3
Maize	30.3	100.0
Brewer’s grain	3.0	50.0
Food wastes	6.1	33.3
Fresh matter diet composition (g kg^{-1})		
Banana pseudostem	669	103
Rice bran	117	60
Vegetables (leaves)	89	206
Maize	43	170
Brewer’s grain	25	265
Food wastes	24	151

Mean ± standard deviation and range (R) for farm distance to the regional market, number of fatteners kept, number of diet ingredients, percentage for housing type, farmers using a feed item and mean for diet composition (raw materials as added before cooking).

26.5 kg), whereas PiDu-sired fatteners were, on average, 6.3 months old (range: 6.0 to 6.8 months) and weighed 58.4 kg (range: 41.0 to 81.5 kg). At this age, products derived from Ban pigs qualify for premium pricing, whereas exotic hogs and their crossbreds are commonly slaughtered at an even higher age and body weight (80 to 100 kg, informal observation).

2.3 *Slaughter and sampling*

Three abattoirs representing typical small-scale butchers (capacity of one to two pigs per day, slaughterers are also engaged in retail) applying common slaughter practice, i.e. bleeding without prior stunning, were selected. A maximum of four pigs per day was slaughtered on 13 slaughtering days in total (mixed genetic groups on 10 days). Pigs were collected the day before slaughter and fasted for at least 12 h prior to slaughter. After bleeding, pigs were scalded by pouring hot water over the body and dehaired manually. Subsequent to evisceration, head, feet and leaf fat was removed and then the carcass weight was recorded. The carcass was split along the backbone and backfat thickness was measured at the level of the last rib and above the *m. gluteus medius*. The loin eye area was recorded on the cross-section of the loin between the 13th and 14th thoracic vertebras. Afterwards, the carcass half was dissected and the lean yield expressed relative to the weight of the dressed carcass half. Samples of the loin (*m. longissimus thoracis et lumborum*, LTL) and ham (*m. semimembranosus*, SM) were excised and dissected, and partly stored refrigerated at 4 °C for meat quality analysis, or frozen at −18 °C for biochemical analysis.

2.4 *Meat quality measurement*

The pH value of fresh meat samples was measured using a hand-held pH meter (pH-STAR, Matthaeus GmbH & Co. KG, Nobitz, Germany), equipped with a glass electrode at 45 min and at 24 h (pH24) post-mortem. Prior to each use, the pH meter was calibrated using buffer solutions at pH 4.6 and 7.0. The electrode was inserted to a depth of 2 cm into LTL and SM. Three measurements were averaged for analysis.

The Japanese Color Score (JCS) was determined at 24 h post-mortem on the cross-section of the LTL and SM, using a scale ranging from 1 (extremely pale) to 6 (extremely dark red). Meat colour (CIE L*, lightness; a*, redness; b*, yellowness) was determined by a CR-400 colorimeter (Konica Minolta Inc., Tokyo, Japan), with a 2° observer angle and illuminant C setting. The colorimeter was calibrated using a white ceramic tile ($Y = 87.1$, $x = 0.3164$, $y = 0.3237$). The average of eight measurements for each sample was used for the analysis.

For the assessment of drip loss after storage, samples of LTL and SM, were weighed and placed in a drainer. The box was tightly sealed with plastic wrap and stored refrigerated at 4 °C until 72 h post-mortem. Then, the weight loss of each sample was recorded and expressed relative to the initial sample weight. Cooking loss of LTL and SM, was determined at 24 h post-mortem by placing samples in polythene bags and cooking them in boiling water to an internal temperature of 85 °C, controlled by an insertion thermometer. Cooking loss was defined as the weight difference after cooking relative to the sample weight before cooking. Additionally, the water holding capacity of the meat was assessed by the filter paper press method. At 24 h post-mortem, small meat samples (~0.3 g) were placed onto filter paper and pressed between two plexiglas blocks for 5 min. Values are given as the ratio of the area of pressed meat over the area of migrated moisture, with higher values indicating an increased water holding capacity. The procedure was repeated three times for LTL and SM.

2.5 *Biochemical analysis*

The determination of water soluble myoglobin was carried out according to Faustman & Phillips (2001) with modifications. Samples (5 ± 0.02 g) were minced, mixed with 20 mL of distilled water, homogenised and centrifuged. The resulting supernatant was filtered by vacuum filtration through a Whatman™ microfiber filter grade GF/C (GE Healthcare, Little Chalfont, UK), then centrifuged at 22,000 × g for 25 min. The absorbance was read at 525 and 730 nm, and the concentration of myoglobin in mg per g wet tissue was calculated following van Laack *et al.* (1996), but without accounting for filtration losses.

The intramuscular collagen level was measured in duplicate on LTL samples according to the AOAC official method 990.26 (AOAC, 1999) for the determination of hydroxyproline with slight modifications. In brief, minced samples (4 ± 0.02 g) were hydrolysed and dried at 105 °C for 16 h. The hydrolysate was then filtered and transferred to 100 mL flasks and diluted to volume with distilled water. Subsequently, 200 μL of filtrate was diluted with 1.8 mL water. Oxidant solution and colour reagent were added as prescribed. Absorbance was read at 558 nm and the hydroxyproline content of the sample was determined using a calibration curve from hydroxyproline. Collagen content was calculated by multiplying the result with a factor of 8, and expressed relative to the wet sample weight.

The determination of intramuscular fat in LTL and SM samples (3 ± 0.1 g), was carried out by the Department of Feed and Product Analyses, National Institute of Animal Sciences in Hanoi, Vietnam, using a 1045/1046 Soxtec™ extraction system (FOSS Analytical AB, Hoeganaes, Sweden). The intramuscular fat concentration was determined gravimetrically, and expressed relative to the wet sample weight.

The fatty acid composition of LTL samples was determined by the Institute of Natural Products Chemistry, Vietnam Academy of Science and Technology in Hanoi, Vietnam. Total intramuscular lipids were extracted according to the method of Bligh & Dyer (1959). Fatty acids were then methylated and injected onto a gas chromatograph (model 6890, Hewlett Packard, New York, NY, USA), equipped with a flame-ionised detector and a DB-23 capillary column (Agilent Technologies, Santa Clara, CA, USA). The results are expressed as a percentage of the total fatty acid methyl esters in the sample and summed up to proportions of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA). The ratio of PUFA to SFA (P/S ratio) and the peroxidisability index, according to Arakawa & Sagai (1986), were additionally calculated.

2.6 *Statistical analysis*

Linear mixed models were fitted using the PROC MIXED function of SAS 9.3 (SAS Institute Inc., Cary, NC, USA). The effects of the genetic group (purebred Ban pigs vs. PiDu-sired crossbreds) and muscle (LTL and SM representing loin and ham, respectively), and their interaction were considered as fixed. Because the exact day of birth was not available in all cases, the application of a covariate for age at slaughter was prevented. Variation due to the slaughter day (13 levels), nested within the slaughter location (three levels), was fitted as a random effect. For drip loss and cooking loss, the initial weight of the sample subjected to measurement was added as a linear covariate. For carcass traits the fixed effect for muscle, and the interaction term were removed from the model, because the effect of muscle did not apply to these traits. Also the models for intramuscular collagen concentration and fatty acid composition simply referred to the fixed effect of genetic group, because the measurements were only conducted on LTL samples. The assumptions of normality of residues and the homogeneity of variances were checked. Five muscle samples (three from purebred Ban pigs and two from PiDu-sired crossbreds) exhibiting dark, firm, dry (DFD) conditions, i.e. pH24 values > 6.0 had to be excluded from the analysis. Least squares means (LSMEANS statement) were compared pairwise using the PDIFF statement and the Tukey-Kramer adjustment (ADJUST = tukey) for unbalanced data. The significant level was set at $P < 0.05$.

3 Results

As expected, the lean meat percentage and meatiness, as expressed in the loin eye area, were significantly lower for traditionally produced Ban pigs compared to PiDu-sired crossbreds slaughtered at the same age (Table 2). The thickness of the subcutaneous fat layer of Ban hogs was significantly lower compared to the backfat thickness of PiDu-sired fatteners.

The rate of pH fall was slightly, but significantly decelerated for Ban pigs compared to PiDu-sired crossbreds and in the SM muscle compared to the LTL muscle (Table 3). The extent of pH fall, as indicated by pH24 values, did not differ among genetic groups or among cuts, negating differences in meat acidification. Several samples of both genetic groups exceeded a threshold of > 6.0 in pH24, and could therefore be prone to develop the DFD condition.

Differences in subjective colour assessment among pork products derived from different genotypes and production systems were not significant (Table 4), but there was a tendency towards lighter, less red Ban loins compared with loins from PiDu crossbreds ($P < 0.1$). The colour of the ham of Ban carcasses scored significantly higher (i.e. darker and redder) compared to the loin of Ban pigs. The subjective assessment was backed by instrumental measurements. The SM of purebred Ban pigs revealed lower CIE L* values, but higher CIE a* and b* values than the LTL muscle. Correspondingly, the myoglobin level of hams was significantly higher compared with the loins of purebred Ban pigs. Within carcasses from PiDu-sired hogs, hardly any differences in subjective colour scores, instrumental colour values, and pigmentation were detected among muscles. Objective meat colour did not differ between the loins from purebred Ban pigs and commercial crossbreds, but ham redness and yellowness were significantly higher for purebred Ban fatteners. Levels of water-soluble myoglobin in SM muscle from Ban purebreds tended to be higher compared to those of PiDu-sired crossbred pigs (+21 %; $P < 0.1$), which could explain the increased a* and b* values of traditionally produced hams.

After 72 h storage at 4 °C, the drip loss of fresh meat did not differ among genetic groups or muscles (Table 5), but it has to be noted that relatively more LTL samples of purebred Ban pigs exceeded a threshold of

Table 2: *Carcass characteristics of traditionally raised purebred Ban and crossbred pigs from by Piétrain × Duroc sires.*

Trait	*Purebred Ban*		*PiDu-sired crossbreds*		*RSD*	*Significance* †
	N	*LSM*	*N*	*LSM*		
Carcass weight (kg)	33	8.2	10	39.6	3.2	***
Lean meat (%)	32	40.9	12	49.5	4.5	***
Backfat at last rib (mm)	33	6.7	12	17.1	3.2	***
Backfat above *m. gluteus medius* (mm)	33	5.8	11	11.5	3.4	***
Loin eye area (cm^2)	33	7.6	9	24.2	2.3	***

N: Number of observations, *LSM*: least squares means, *RSD*: standard deviation of residuals.
† Significance level: ***, $P < 0.001$.

Table 3: *Postmortem glycolysis for muscles (m. longissimus thoracis et lumborum, LTL and m. semimembranosus, SM) from traditionally raised purebred Ban and pigs from by Piétrain × Duroc (PiDu) sires.*

Trait	*Muscle*	*Purebred Ban*		*PiDu-sired crossbreds*		*RSD*	*Significance* †		
		N	*LSM*	*N*	*LSM*		*G*	*M*	G × M
pH 45 min	LTL	33	6.32	12	6.20	0.23	*	**	ns
	SM	33	6.55	12	6.36				
pH 24 h	LTL	30	5.57	10	5.60	0.10	ns	ns	ns
	SM	32	5.58	11	5.57				

N: Number of observations, *LSM*: least squares means, *RSD*: standard deviation of residuals.
† Significance level for the effects of genetic group (G), muscle (M), and their interaction (G × M): **, $P < 0.01$; *, $P < 0.05$; ns, $P > 0.05$.

Table 4: *Postmortem glycolysis for muscles (m. longissimus thoracis et lumborum, LTL and m. semimembranosus, SM) from traditionally raised purebred Ban and pigs from by Piétrain × Duroc (PiDu) sires.*

Trait †	*Muscle*	*Purebred Ban*		*PiDu-sired crossbreds*		*RSD*	*Significance* ‡		
		N	*LSM*	*N*	*LSM*		*G*	*M*	G × M
JCS	LTL	33	3.10 ^{y}	12	3.66	0.60	ns	**	*
	SM	33	3.89 ^{x}	12	3.81				
CIE L*	LTL	33	47.34 ^{x}	11	46.38	2.36	ns	**	*
	SM	33	43.66 ^{y}	11	45.49				
CIE a*	LTL	33	8.76 ^{y}	12	9.04	1.55	ns	***	*
	SM	33	12.05 ^{ax}	12	10.38 ^{b}				
CIE b*	LTL	33	2.59	12	1.73	1.02	***	***	ns
	SM	33	3.63	12	2.51				
Mb (mg/g)	LTL	33	0.79 ^{y}	12	0.92	0.28	ns	*	**
	SM	31	1.12 ^{x}	12	0.89				

N: Number of observations, *LSM*: least squares means, *RSD*: standard deviation of residuals.
† JCS: Japanese Colour Score ranging from extremely light (1) to extremely dark red (6), CIE L*: lightness, CIE a*: redness, CIE b*: yellowness, Mb: water-soluble myoglobin.
‡ Significance level for the effects of genetic group (G), muscle (M), and their interaction (G × M): **, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; ns, $P > 0.05$. Where the interaction is significant, different superscripts represent significant differences among muscles (x,y; within genetic group) or among genetic groups (a,b; within muscle) at $P < 0.05$.

7 % drip loss (33 % for purebred Ban pigs vs. 8 % for PiDu-sired crossbreds). Furthermore, cooking losses at 24 h post-mortem did not differ. In contrast, meat from traditionally produced Ban carcasses exhibited a significantly lower ratio of expressible to retained moisture at 24 h post-mortem according to the filter paper press method compared with meat from PiDu-sired crossbreds fattened under semi-extensive production conditions.

Although not significant, the intramuscular collagen levels of the LTL muscle of purebred Ban pigs tended to be higher when compared to PiDu-sired barrows (+18 %; $P < 0.1$; Table 6).

In Table 6, it is also shown that muscles of purebred Ban pigs had considerably lower intramuscular fat levels on a wet tissue basis compared with commercially produced PiDu crossbreds (−51 % and −42 % relative to LTL and SM of PiDu crossbreds, respectively).

The composition of lipids of the LTL muscle revealed some remarkable differences between product categories (Table 7). Although the small difference encountered in the proportion of stearic acid (C18:0) was significant, the overall proportion of SFA did not differ among genetic groups. The most abundant fatty acid in pork from both sources was oleic acid (C18:1 n-9), which was significantly higher in the LTL of PiDu-sired fatteners, resulting in a considerably higher concentration of MUFA in the loin of the commercial crossbreds. In contrast, linoleic acid (C18:2 n-6) was detected at a significantly higher percentage in the traditional meat product. Consequently, the share of PUFA, the P/S ratio, and also the peroxidisability index, were significantly higher in traditional Ban pork.

4 Discussion

4.1 Distinguishing carcass characteristics of traditionally produced Ban pigs

The marked differences in carcass weight of Ban pigs when compared to commercial crossbreds is expected and mainly attributable to the effect of sire breeds and the long-term selection on growth and lean meat production in the paternal lines. The Piétrain breed is particularly known for marked muscling and a large loin eye area, even when compared to other modern breeds (Gil *et al.*, 2008). The superior carcass yield of PiDu-sired porkers may have been further enhanced by feeding improved diets. During the study period, the diets of local Ban pigs were mainly based on banana pseudostem and rice bran. Similar diet compositions were reported for traditional pig husbandry systems of other regions of the SEAM (Nakai, 2008; Phengsavanh *et al.*, 2010; Riedel *et al.*, 2012). Banana pseudostem is readily available around the farm premises, but characterised by low percentages of dry matter, crude protein and gross energy. All farmers raising crossbred fatteners added ground maize grain to the diet, enhancing the dry matter percentage and the gross energy content of the rations. Also vegetable leaves and brewer's grains were important ingredients in most of the preparations for commercial crossbreds, where particularly the brewer's grains represented an important source of dry matter, gross energy and crude protein. Using data from the Animal Feed Resources Information System (2016), it could be estimated that crossbreds consumed 1.8 times more dry matter on a daily basis than Ban pigs. As a result, commercial fatteners could have realised an estimated 2.3 and 2.0 times higher daily intake of crude protein and gross energy, respectively. However, no nutritive analyses of the diets have been carried out in this study, and the composition and nutritive value of diets may have varied considerably on household level. Purebred Ban fatteners revealed a reduced dorsal fat layer compared to commercial crosses, whereas, generally, the opposite is found when comparing slow-growing breeds with modern genotypes at equal age (e.g., Wood *et al.*, 2004), but this can at least be partly explained by the exceptionally low slaughter weight of Ban pigs. For older Ban pigs, a rapid increase in fat deposits would be expected, as suggested by the results of Hau (2008), where purebred Ban pigs displayed a backfat thickness of 30 mm at an age of approximately 10 months. This indicates that timing of slaughter in relation to maturity is crucial for the success of marketing of specialty Ban carcasses, because for premium markets lean carcasses at lower body weights are requested (10 to 15 kg live weight and a minimum of 40 % of lean meat according to Le *et al.*, 2016). Heavier and fatter Ban pigs can only be sold in rural markets at lower prices per kg of live weight.

4.2 Distinguishing physico-chemical traits of traditionally produced Ban pork

Early pH fall and ultimate pH are widely used as indicators for undesired meat conditions such as pale, soft, exudative (PSE) and DFD pork. The rate of pH fall in relation to high pre-rigor temperature in the muscle can have pronounced effects on post-mortem metabolism, as well as protein denaturation, and, consequently, on meat quality, and several studies documented breed differences in pH fall and ultimate pH when comparing slow-growing and high performing breeds (Chang *et al.*, 2003; Renaudeau & Mourot, 2007). In the present study, the fall of the early post-mortem pH was acceler-

Table 5: *Water binding properties for muscles (m. longissimus thoracis et lumborum, LTL and m. semimembranosus, SM) from traditionally raised purebred Ban and pigs from Piétrain × Duroc (PiDu) sires.*

Trait †	*Muscle*	*Purebred Ban*		*PiDu-sired crossbreds*		*RSD*	*Significance* ‡			
		N	*LSM*	*N*	*LSM*		*β*	*G*	*M*	G × M
Drip loss (%)	LTL	30	6.07	11	6.12	1.26	**	ns	ns	ns
	SM	30	5.84	11	6.29					
Cooking loss (%)	LTL	33	30.37	12	30.02	3.72	***	ns	ns	ns
	SM	33	31.28	12	29.58					
FPP (cm^2/cm^2)	LTL	33	0.36	12	0.42	0.04	–	***	ns	ns
	SM	33	0.39	12	0.43					

N: Number of observations, *LSM*: least squares means, *RSD*: standard deviation of residuals.

† Drip loss was measured at 72 h post-mortem and cooking loss at 24 h post-mortem. FPP: moisture expressible by the filter paper press method.

‡ Significance level for the effects of sample weight as covariate (*β*), genetic group (G), muscle (M), and their interaction (G × M): ***, $P < 0.001$; **, $P < 0.01$; ns, $P > 0.05$.

Table 6: *Intramuscular fat and collagen concentrations for muscles (m. longissimus thoracis et lumborum, LTL and m. semimembranosus, SM) from traditionally raised purebred Ban and pigs from Piétrain × Duroc (PiDu) sires.*

Trait †	*Muscle*	*Purebred Ban*		*PiDu-sired crossbreds*		*RSD*	*Significance* ‡		
		N	*LSM*	*N*	*LSM*		*G*	*M*	G × M
IMF (%)	LTL	30	1.63	11	3.31	0.90	***	ns	ns
	SM	30	1.80	12	3.08				
IMC (%)	LTL	31	2.50	12	2.04	0.66	ns	–	–

N: Number of observations, *LSM*: least squares means, *RSD*: standard deviation of residuals.

† IMF: Intramuscular fat, IMC: intramuscular collagen.

‡ Significance level for the effects of genetic group (G), muscle (M), and their interaction (G × M): ***, $P < 0.001$; ns, $P > 0.05$.

Table 7: *Lipid composition of muscle (m. longissimus thoracis et lumborum) from traditionally raised purebred Ban and pigs from Piétrain × Duroc (PiDu) sires.*

Trait †	*Purebred Ban*		*PiDu-sired crossbreds*		*RSD*	*Significance* ‡
	N	*LSM*	*N*	*LSM*		
C16:0 (%)	24	23.50	12	24.01	1.16	ns
C18:0 (%)	24	13.10	12	11.65	1.34	**
C16:1 n-7 (%)	24	1.51	12	2.44	0.64	**
C18:1 n-9 (%)	24	38.49	10	46.89	4.34	***
C18:2 n-6 (%)	24	17.39	11	10.47	4.28	**
∑SFA (%)	24	38.48	12	38.52	2.10	ns
∑ MUFA (%)	24	41.59	11	49.43	4.70	**
∑ PUFA (%)	24	22.13	11	12.79	6.45	**
P/S ratio	24	0.58	11	0.33	0.18	**
Peroxidisability index	23	29.70	11	17.02	9.03	**

N: Number of observations, *LSM*: least squares means, *RSD*: standard deviation of residuals.

† SFA: Saturated fatty acids, MUFA: monounsaturated fatty acids, PUFA: polyunsaturated fatty acids. The P/S ratio was calculated as ∑ PUFA/∑ SFA and the peroxidisability index was calculated according to Arakawa & Sagai (1986).

‡ Significance level: ***, $P < 0.001$; **, $P < 0.01$; ns, $P > 0.05$.

ated for PiDu-sired crossbreds compared to Ban pigs, however, it is suggested that these differences in pH development are practically not relevant because pork from PiDu-sired crossbred exhibited no further indications of the PSE condition. Ultimate pH has a marked influence on consumer perception of pork eating quality, but currently no differences in incidence of meat defects between the traditional Ban pork and pork from semi-extensively reared crossbreds are expected. The relative advantage of local Ban pork in terms of the absence of PSE might be more pronounced, if compared to pork from industrially produced completely exotic crossbreds segregating for the halothane gene (Webb & Casey, 2010).

Rather than being a consequence of combined rearing and genetic effects, sporadically occurring high pH values at 24 h post-mortem in both product categories could indicate a depletion of glycogen reserves prior to slaughter as a consequence of stress and higher physical activity of the pigs (Henckel *et al.*, 2002). Under the prevalent slaughtering conditions, genetic disposition for reduced meat quality is expected to be rather reflected in an increased incidence of DFD than of PSE. The frequency of LTL muscles exhibiting ultimate pH values > 6.0 amounted to 9 % for Ban fatteners and to 17 % for the crossbreds. Because of the small sample size, the difference in proportions between the groups was not significant ($P = 0.598$; unpublished), but should be further investigated. The higher pH of DFD meat could promote microbial growth and negatively impact meat safety, particularly under the conditions of informal pork value chains, where a continuous cold chain cannot be safeguarded.

The preference of consumers is substantially influenced by product appearance, especially by its colour. However, meat colour differences of fresh meat from the two genetic groups were small in this study, and not sufficient for effectively discriminating the product categories. It is questionable whether the differences in instrumental colour found when comparing the ham of both genetic groups are detectable by human vision, given that the difference in JCS was non-significant. Similarly, Renaudeau & Mourot (2007) observed no differences in meat colour of the *longissimus dorsi* muscle when comparing Caribbean Creole pigs to a commercial breed at a body weight at slaughter of 90 kg, but significantly lower L* and b* values for the *semimembranosus* muscle of the slow-growing Creole breed. Meat lightness and redness differed particularly when comparing Iberian pig lines to a commercial crossbred (Estévez *et al.*, 2003, 2006), with lower L* values and higher a* values for Iberian pork. Estévez *et al.* (2003) detected significant breed differences for the haem pigment content of *longissimus dorsi* between Iberian pigs and a commercial crossbred, which may underlie the differences in colour. Yet, breed effects on meat colour and pigmentation might be exaggerated when slow-growing breeds are slaughtered at a higher age, because haem pigment levels and the redness of the meat are supposed to increase with age (Trefan *et al.*, 2013). For the traditionally produced carcasses, a strong colour gradient was observed. The differences in meat colour between LTL and SM of purebred Ban pigs were backed by differences in pigment content, which could be related to the divergent function and metabolic profiles of muscles. In line with this assumption, Gil *et al.* (2008) found that oxidative traits, including pigment content, were more pronounced in the *semimembranosus* muscle compared to the *longissimus thoracis* muscle, which had a higher glycolytic activity.

The ability of meat to retain water is associated with purge loss and processing quality, but also with the sensory perception of fresh and cooked meat. Traditionally produced Ban pork did not reveal improved water binding properties when compared to meat from the exotic sired crosses also rather extensively produced in the same region. Caribbean Creole had significantly reduced drip and cooking losses compared to Large White pigs under standardised experimental conditions (Renaudeau & Mourot, 2007). It should to be noted that in the previously mentioned study, the effect of slaughter weight was accounted for, but age was a confounding factor. When slaughtered at the same age, Duroc exhibited higher drip losses than traditional British breeds, but Large White revealed the lowest purge loss and did not differ from traditional British breeds (Chang *et al.*, 2003). Drip loss as an indicator for water holding capacity is closely related to the post-mortem pH development (Schäfer *et al.*, 2002). The absence of pronounced differences in post-mortem pH development between pork from both production contexts in the present study might, thus, partly explain the absence of significant differences in drip and cooking loss. However, factors such as proteolytic activity, connective tissue characteristics, and the amount of intramuscular fat could also contribute to water mobility within meat during storage and water loss during cooking (Pearce *et al.*, 2011). Only in a controlled experiment the water binding potential of Ban meat in relation to pork from conventional genotypes could be determined.

Wheeler *et al.* (2000) showed that the tenderness scoring of pork muscles is influenced by collagen properties in relation to proteolysis and sarcomere length. In the present study, intramuscular collagen levels tended to increase for traditionally produced LTL from Ban pigs. Instrumentally assessed tenderness between traditional British pig breeds and modern lines differed significantly, with *longissimus dorsi* derived from Duroc being the toughest, followed by Tamworth and Large White samples, which exhibited similar values, and Berkshire, which revealed the most tender meat (Chang *et al.*, 2003). Whereas Western consumers favour more tender meat (Moeller *et al.*, 2010), to the best of our knowledge no organoleptic studies on pork including a Vietnamese test or consumer panel are available, which makes it difficult to create assumptions on acceptability based on intramuscular collagen levels. Additionally, the variation in intramuscular collagen would probably not allow for the discrimination of product categories by sensorial assessment.

4.3 Distinguishing lipid characteristics of traditionally produced Ban pork

In contrast to the present findings, most studies comparing slow-growing traditional genotypes to modern breeds reported higher intramuscular fat contents for the former (e.g., Estévez *et al.*, 2003; Renaudeau & Mourot, 2007). Wood *et al.* (2004) pointed towards a more complex situation, with increased marbling fat in Duroc pigs and traditional Berkshire compared to Large White and Tamworth pigs slaughtered at equal age. For intramuscular fat accumulation, additional factors besides breed have to be taken into account. As previously mentioned, the diets of Ban pigs were characterised by a low nutrient density, while for PiDu-crossbreds an insufficient supplementation with essential amino acids could be proposed. Deficiency in essential amino acids is common for homemade diet preparations for pigs on smallholder farms in Vietnam (Pham *et al.*, 2010). Thus, periods of restricted alimentation through a high dilution of nutrients and a low maturity at slaughter age could have specifically contributed to the low intramuscular fat percentage of pork derived from traditionally raised Ban pigs, while a deficit in lysine in diets for PiDu-sired crossbreds could have resulted in their comparatively high intramuscular fat concentration (Da Costa *et al.*, 2004). In line with the results obtained for the commercial crossbreds in the present study, Luc *et al.* (2014) observed high intramuscular fat levels of 2.8 % for commercial crossbred barrows raised under smallholder conditions in northern Vietnam. This value is slightly lower compared to the values for PiDu-sired crossbreds presented herein, which could be due to the higher proportion of exotic blood (25 % Mong Cai and 75 % exotic) in the crosses investigated by Luc *et al.* (2014). In Ban pigs, compensatory fat deposition during the later stages of maturation could result in highly marbled meat cuts, as indicated by dramatically increased subcutaneous fat deposits reported by Hau (2008). The impact of the intramuscular fat percentage on eating quality is controversial. Ciobanu *et al.* (2011) indicated that correlations between consumer acceptability and intramuscular fat level across several studies were relatively high, ranging from 0.54 to 0.68, but Moeller *et al.* (2010) hardly detected any effect on consumer acceptability below a threshold level of 5 to 6 % of intramuscular fat.

The reasons for the remarkable differences in fatty acid profiles between product categories cannot be traced back with certainty because both aspects, genetic and nutritional, contribute to variation in the fatty acid composition. The fatty acid pattern of the traditional product, however, resembles more that of leaner modern pig breeds than slow-growing genotypes, whereas the lipid composition of LTL of PiDu crossbreds was closer to that found for muscles of local European purebreds (Estévez *et al.*, 2003, 2006; Renaudeau & Mourot, 2007). Więcek *et al.* (2011) showed that feed restriction can affect the fatty acid composition of *longissimus thoracis* and increase the P/S ratio. Under traditional extensive husbandry conditions, frequently occurring fluctuations in feed quantity and quality could, therefore, contribute to the specific fatty acid pattern of the LTL of Ban pigs. Furthermore, it is assumed that the limited development of the fat deposits of Ban pigs could have contributed to the fatty acid composition of the loins of traditionally produced Ban pigs, because dietary PUFA get less ‘diluted’ by de novo synthesised fatty acids. Variations in lipid quality have implications for the shelf life, technological quality, and also health attributes of pork products, but trade-offs between these domains exist. Because replacing SFA with PUFA most probably decreases the risk of coronary heart diseases (FAO, 2010), the higher share of PUFA in Ban pork could be considered as beneficial. However, the higher share of PUFA in traditional pork was at the expense of the proportion of MUFA, but not of SFA compared with the commercial product, therefore health benefits from the consumption of traditionally produced Ban meat are arguable (ibid.). The significantly increased peroxidisability index of the traditional pork product compared to commercial meat, however, indicated a higher number of double bonds in fatty acids of LTL in Ban pork, which could increase its proneness to oxidation. Therefore, specific attention has to be put on the shelf life of fresh traditional products from Ban pigs, especially when they are transported over long distances. With respect to the processing and storage characteristics of manufactured goods from Ban, the lipid composition of the subcutaneous tissue is of higher importance than the composition of the intramuscular lipids, however the former was not the subject of the present study.

5 Conclusions and implications

The marketing of pork derived from local pig breeds as a specialty food item could be an important source of additional income for rural smallholders of mountainous northern Vietnam, provided the products are distinguishable from commodity pork. Exemplified for the Vietnamese Ban breed, this study demonstrated that traditionally produced local pork indeed exhibits distinctions compared to pork from crossbreds produced under semi-extensive conditions. It was shown that, besides smaller cut dimensions and a reduced amount of backfat, possibly serving as quality cues in gourmet gastronomy (Phuong *et al.*, 2014), particularly features related to lipid characteristics allow for a clear discrimination of traditionally produced local pork. Other important traits, for instance the ultimate pH, were similarly expressed in both product types; in this case however, the definite approval of the null hypothesis was impeded due to the restrictions in sample size and statistical power. A lower incidence of the DFD defect in Ban pork could not be excluded. These peculiarities could provide the basis for a marketing concept to fill market niches on the increasingly commodified pork markets of Vietnam. The present study focused on technological meat quality traits, but follow-up research should focus on sensory analyses allowing inference to be drawn about the acceptability of the products. The differences in meat quality observed herein are supposed to be largely related to genetic background and its covariance with regional management and feeding practices. These confounding factors (diet, housing, and particularly slaughter weight) and between-household variation aggravate the establishment of causal relationships with respect to the impact of genetic background on meat quality, which is one limitation of the present study. The context in which the pork is produced is highly relevant for the evaluation of the products under the practical conditions of regional production; therefore, an observational design was preferred over a cross-classified design for the purpose of the current study. These considerations also imply that the transfer of these results to pork products of other SEAM production conditions, including (semi-) intensively produced pork derived from crosses between exotic breeds, is prevented. Further investigations in this direction are encouraged.

Finally, there are still major constraints for designing a value chain for specialty pork that would contribute to the rural development of the Vietnamese uplands and elsewhere in the SEAM. For instance, it remains questionable whether the most disadvantaged producers are capable of meeting the market demand for local pigs in terms of volume, timeliness and quality, and whether they would actually benefit from price premiums in view of high transaction costs in complex value chains. However, the present results may contribute to connecting marginalised farmers from ethnic minorities of the mountainous areas of northern Vietnam to remunerative urban ‘high-end’ pork markets in the lowlands and hence to creating added value for the producers (Le *et al.*, 2016). The characterisation of traditionally produced Ban pork by technological and functional quality attributes and its discrimination from commodity produce allow establishing a common understanding of Ban pork quality along the value chain from farmers to the final consumers. This common understanding of the product could facilitate the development of production protocols and branding. The latter could provide protection against free-riders, help to overcome information asymmetries, and, as a consequence, safeguard the stability of outlets and price premiums. Such approaches could thereby support the *in situ* conservation of local Southeast Asian pig genetic resources.

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