Korean J. Food Sci. An.
Vol. 33, No. 4, pp. 508~514(2013)
DOI http://dx.do.org/10.5851/kosfa.2013.33.4.508

ARTICLE

Differences in the Taste-active Compounds between Hanwoo *Longissimus* and *Semitendinosus* Muscles and Its Comparision with Angus *Longissimus* Beef Muscle

Dashdorj Dashmaa, Jieun Yang, Hoa Van Ba, Kyeong-Seon Ryu, and Inho Hwang*
Department of Animal Science, Chonbuk National Univeristy, Jeonju 561-756, Korea

Abstract

Taste-active compounds (e.g., amino acids and nucleotides) play an important role in contribution to the gustatoty sensation of food. The current study aimed to examine the differences in taste-active compounds between different beef muscles, breeds and aging periods. We have chosen the *longissimus dorsi* and *semitendinosus* muscles of Hanwoo breed and *longissimus dorsi* muscle of Angus breed for the investigation of the aforementioned compounds. Hanwoo muscles were aged for 7 or 28 d, and Angus samples were aged for 28 d at 4°C. Results revealed that 8 out of the 18 detected free amino acids (FAA) showed significant ($p<0.05$) differences between the two Hanwoo muscles. Twelve FAAs showed aging effect ($p<0.05$) in which the amounts of 8 FAAs significantly increased as aging time increased. Inosine 5-monophosphate (IMP), hypoxanthine (Hx) and inosine showed significant ($p<0.05$) differences between the Hanwoo muscles, aging resulted in an increase in amounts of these nucleotides. Hanwoo beef had significantly ($p<0.05$) higher total amount of sweet amino acids than the Angus ones in that 15 amino acids showed differences ($p<0.05$) between the two breeds. Amounts of guanosine 5-monophosphate (GMP) and Hx were significantly higher ($p<0.05$) for Angus beef. Current study indicated that muscle type, breed and aging period had large variations in free amino acid and nucleotide contents, which may subsequently affect the taste attributes of cooked beef.

Key words: amino acid, nucleotide, chiller aging, muscle, breed

Introduction

As Korea has developed economically, the demand for meats, in particular for more palatable meats, has increased compared to that before the 1980s (Jo *et al.,* 2012). Furthermore, with a rapid increase in per capita meat consumption therefore the country is not yet self-sufficient in beef production, more than half of consumer demand is met by imports from Australia, USA, New Zealand, Mexico, and Canada (Jo *et al.,* 2012). Previous workers (Robbins *et al.,* 2003; Savell *et al.,* 1987) indicated that sensory traits such as flavor and tenderness are the most important criterion of acceptability and palatability of beef affecting consumer purchasing decisions. Amongst them, the characteristics of beef flavor are combined by the basic tastes and odors (Motram, 1994). There are great number of taste-active compounds in meat such as free amino acids, nucleotides and minerals which contribute to the tastes of meat (Nishimura, 1998). The taste is constituted by sweetness, saltiness, bitterness, sourness and a further basic sensation called 'umami' has been described as the taste of monosodium-glutamate (MSG) and nucleotides, such as inosine 5-monophosphate (IMP) and guanosine 5-monophosphate (GMP), hypoxanthine (Hx) and inosine (Mateo *et al*.,1996). The taste-active compounds in beef not only contribute to the tastes but also further react with each other generating the aroma components through some pathways such as Maillard reaction (Mottram, 1994). Furthermore, earlier workers (Koutsidis *et al.,* 2008b; Nishimura, 1998) reported that chiller aging of meat led to the increase in concentrations of taste-active compounds which improved the tastes of meat. However, it has been reported that the time and amount of reaching maximum or minimum in meat varied depending on pre-slaughter and post-slaughter factors (Koga *et al*., 1987; Koutsidis *et al*., 2008a; Sasaki *et al*., 2007).

More to the point, Angus beef cattle imported from overseas is very common beef in Korea and is getting more attention by Korean consumers after the Korean native

*Corresponding author: Inho Hwang, Department of Animal Science, Chonbuk National University, Jeonju 561-756, Korea. Tel: 82-63-270-2605, Fax: 82-63-270-2605, E-mail: inho.hwang@jbnu.ac.kr

cattle beef (Hanwoo). The beef exporters have increasingly adapted to meet the specific quality preferences of Korean consumers. Even though the increasing import or despite price differences between Hanwoo beef and imported beef, it appears that Korean consumers prefer beef from Hanwoo to imported beef because they believe that the most important factors for branding Hanwoo beef would be taste and safety (Hwang *et al.,* 2010; Kim *et al*., 2009).

Up to present, very limited scientific information regarding the effect of Hanwoo muscle type and aging time on the taste-active compounds as well as in comparision with Angus beef is available. Taken the rationale, the current study was designed to examine the differences in taste-active compounds between Hanwoo muscles at different chiller aging periods and in comparision with Angus beef breeds.

Materials and Methods

Hanwoo heifers (n=20) and Angus heifers (n=20) were used as experimental models in the present investigation. Both Hanwoo and Angus cattle breeds were finshed on a same whole crop barley silage diet at feedlots of farms. The Hanwoo cattle were transported to a commercial abattoir where they were slaughtered by conventional procedure. After slaughter, all of the carcasses were immediately transferred to chilled rooms for 24 h. The next day, the left side of carcass was ribbed between the 13th rib and the first lumbar vertebrae. Carcasses were evaluated by official grader for fat thickness, loin-eye area and beef marbling score according to the Korean Carcass Grading Standard (National Livestock Cooperatives Federation, NLCF, 2004). *Longissimus dorsi* (LD) muscle with quality grade 1 and *semitendinosus* (ST) muscle were taken from the right sides of the carcasses, vacuum packaged and transferred to the Meat Science Laboratory of the Chonbuk National University under chilling condition. Each muscle sample was divided into two equal potions and vacuum packaged, a half was allotted to the 7 d aging and the remaining half was allotted to the 28 d aging group. The aging of the samples was done at 4ºC in a chiller room, and then stored at -20ºC in a freezer for further use. After slaughtered by conventional procedure, the LD muscle (quality grade 1) of Angus cattle with were also taken, vacuum packaged and transported from Australia to Incheon international airport (South Korea) under chilling condition (4ºC). After that the Angus beef samples were immediately transported to the Meat Science Laboratory of the Chonbuk National University and aged at 4ºC in a chilling room for additional days to reach an aging period of 28 d postmortem as aforementioned Hanwoo samples. After chiller aging, the muscle samples of both breeds were carefully trimmed off from all visual fats and used for measurements of taste active-components including free amino acids and nucleotides.

Free amino acid analysis

The free amino acids (FAAs) in samples from Hanwoo and Angus beef cattle were extracted using procedure as described by Aristoy and Toldra (1991). The muscle sample (1 g each) was homoginzed in 0.01 N HCl by three strokes of 20 s each at 4ºC and centrifuged at 10,000 *g* for 20 min at 4ºC. The supernatant was filtered and stored at -80ºC until use. Internal standard (10 μL, 1 nmol norvaline) was added to the samples and allowed for 30 min at room temperature after deproteinization with 690 L of acetonitrile, then centrifuged at 10,000 *g* for 15 min. The free amino acids in the extracted samples were analyzed using a RP-HPLC 1200 system (Agilent Technologies Inc., USA) equipped with a diode array detector (DAD) following the method as described by Woodward and Henderson (2007). The chromatographic peaks were separated on a Symmetry C18 column (4.6 mm × 150 mm column packed with 5 μm particles, Agilent Technologies Inc., USA). Prior to analysis, 200 μL of the extracted samples (each) was derivatised by o-phtalaldehyde (Germany) for the primary amino acids and 9-fluorenylmethoxycarbonyl chloride (Germany) for the secondary amino acids. Solvent A was 10 mM Na_2HPO_4: 10 mM $Na_2B_4O_7$: 0.5 mM NaN_3 at pH 8.2 and solvent B was acetonitrile: methanol: water (45: 45:10 v/v). The separation was achieved in 21 min; linear gradient 2% B for 5 min, 2-57% B for 8 min and 57-100% for 4 min then maintain for 3 min and re-equilibrated with 100% A for 2 min before next sample injections. The amino acids were identified based on the retention time of the standard amino acid mixture (Agilent Technologies, Germany), and the amino acids were quantitated by either using external standard or by using norvaline (Agilent Technologies, Germany) as an internal standard, while the secondary amino acids were quantitated using sarcosine (Agilent Technologies, Germany) as another internal standard. Individual free amino acid values were expressed as μmol/g of fresh meat.

Nucleotide analysis

Nucleotide content in the muscle samples were extracted and analyzed using the method of Flores *et al.* (1999). The

muscle sample (5 g each) in 1 N HCl by three strokes of 10 s at 14,000 *g* and centrifuged at 10,000 *g* for 20 min at 4°C. The supernatant was neutralized with 6 M potassium hydroxide to pH 5.5, then was filtered through a 0.45 μm membrane. The neutralized filtrates were kept at -20°C until analysis. The nucleotides in the samples were analyzed using a high performance liquid chromatography (HPLC, Agilent Technologies). The chromatographic peaks were separated on a Symmetry C18 column (4.6×250 mm, WAT054275 Waters, Ireland). Solvent A was 0.04% (v/v) triethylamine in 10 mM phosphate buffer at pH 5.5 and solvent B was HPLC grade water/ acetonitril (40:60). The specifications were as following; Flow rate 1 mL/min, linear gradient 0-15% B for 12 min and 15-100% B for 4 min and then maintained for 10 min and re-equilibrated with 100% A for 10 min before next sample injection. The temperature was controlled at 40°C. The peaks were identified by comparing the retention times between sample peaks with the external standards and quantitated by using purine (Sigma-Aldrich, USA) as an internal standard.

Statistical analysis

Means of free amino acid and nucleotide contents were evaluated by using the analysis of variance following a general linear model. Mean values and standard errors are reported on means within different muscles and breeds which aged 7 and 28 d. Comparisons of means were analyzed using the Duncan's multiple-range test at the significance level of 0.05 (SAS, 2007).

Results and Discussion

Effect of different Hanwoo muscles and aging periods on the free amino acid content

A total of 18 free amino acids (FAA) were identified in LD and ST muscles of Hanwoo beef (Table 1). The FAAs usually contribute to the monosodium glutamate-like (MSG-like), bitter and sweet taste. The FAAs are also divided into several classes due to the similar taste qualities (Kato *et al.,* 1989; Nishimura and Kato, 1988) as shown in Table 1. For instance, the acidic and amidic amino acids for the MSG-like taste; the hydroxylic and some aliphatic amino acids such as Ala, Gly and Pro for the sweet taste; the aromatic, basic and other aliphatic amino acids such as Iso, Leu and Val for the bitter taste; and those containing a sulphur atom have a sulfuric note (Koga *et*

Table 1. Free amino acid content (μmol/g) of LD and ST muscles of Hanwoo breed during chiller aging

Free amino acids	Longissimus dorsi		*Semitendinosus*		SEM[1)]	F value		
	7 d	28 d	7 d	28 d		Muscle	Aging	Muscle*Aging
Aspartic acid (Asp)	nd	0.57	nd	0.71	0.14	0.64	0	0
Glutamic acis (Glu)	0.75	1.99	0.68	1.89	0.23	0.14	27.25***	0.18
Asparagine (Asn)	0.82	0.65	0.22	0.45	0.05	60.23***	0.81	18.63***
Glutamine (Gln)	4.2	3.37	2.9	4.26	0.45	0.04	0.72	7.02**
Total (MSG-like)[2)]	5.77	6.01	3.8	6.6	0.58	0.75	11.42*	7.29*
Alanine (Ala)	4.06	5.38	7.2	9.17	0.72	27.63***	6.69*	0.27
Glycine (Gly)	0.81	1.89	1.52	0.79	0.33	38.26***	26.34***	9.5**
Serine (Ser)	0.29	1.76	0.73	1.5	0.15	0.28	37.77***	3.66*
Theonine (Thr)	0.93	0.7	0.3	ND	0.16	5.96*	0.98	0
Proline (Pro)	0.44	1.07	1.03	1.89	0.07	10.59**	53.8***	0.54
Total(Sweet)	6.53	10.8	10.78	13.35	0.91	0.11	0.01	0.71
Arganine (Arg)	0.18	0.56	0.44	0.48	0.07	1.73	9.01**	6.05*
Lysine (Lys)	1.01	1.03	0.46	0.7	0.08	28.94***	2.42	2.38
Phenylalanine (Phe)	1.57	0.81	nd	nd	0.09	0	27.91**	0
Tyrosine (Tyr)	0.07	0.18	0.08	0.38	0.08	2.0	7.73*	1.39
Isoleucine (Ile)	0.98	2.01	0.32	1.92	0.13	9.79**	9.74***	5.82
Leucine (Leu)	1.56	1.57	1.56	1.58	0.01	0.02	0.02	0.02
Valine (Val)	2.12	1.12	7.88	1.31	0.79	13.37***	21.66***	11.69**
Total (Bitter)	7.49	7.28	10.74	6.37	0.88	0.07	5.63*	0.088
Cystine (Sys)	0.27	1.34	0.47	0.95	0.15	0.66	43.56***	6.1*
Methionine (Met)	1.05	1.49	1.29	1.85	0.23	0.81	7.91*	8.04*
Total (Sulphur)	1.32	2.83	1.76	2.8	0.24	0.07	67.68***	6.67*
Total amino acids	22.1	28.45	27.08	29.81	0.22	3.9	8.56*	0.28

[1)]SEM: Standard error of mean, [2)]Monosodium glutamate-like taste. nd: not detected.
*p<0.05; **p<0.01; ***p<0.001

al., 1987; Nishimura, 1998). Our results revealed that the muscle had a significant effect on 8 of the 18 detected FAAs. In particular, Asn, Gln, Thr, Iso and Lys were significantly higher in LD muscle, whereas the Ala, Val and Pro were significantly higher in ST muscle. Earlier workers (Feidt *et al.,* 1996) also reported that the release of FAAs was strongly muscle-dependent. The muscle enzymes such as calpains and cathepsins which all are able to destroy myofibrillar proteins to release small peptides and FAAs (Gerard *et al*., 1988). Also, the alanyl aminopeptidase and aminopeptidase B activity was found different between LD and *biceps femoris* muscles (Flores *et al.,* 1996). The authors have suggested that the different enzyme activities were responsible for the differences in release of amino acids among the examined muscles (Feidt *et al.,* 1996). In the present study, although the enzyme activity has not been measured however it could be suggested that the differences in the amounts of FAAs are probably due to the differences in muscle enzyme activity between LD and ST muscles.

For the aging effect, our results depict that 12 amino acids show chiller aging effect ($p<0.05$). Except for Asn, Glu, Thr, and Lys the other remaining FAAs showed significant differences ($p<0.05$) between the LD and ST muscles (Table 1). Particularly, the amounts of Glu, Ala, Ser, Pro, Ile, Met and Sys in both muscles aged for 28 days were significantly higher than those in the corresponding samples aged for 7 d. Whereas, the amounts of some amino acids (e.g.,Val) in both muscles showed significant decrease as aging time increased. The concentrations of most FAAs were partly similar to the values reported for beef; Feidt *et al*. (1996) and Koutsidis *et al*. (2008b) also reported that an increase in free amino acids in beef of 22-33% over 14 d of conditioning at 2°C. Also Koutsidis *et al*. (2008b) observed that Glu remained relatively stable between muscles and during aging. Nishimura *et al.* (1988) reported that rates of increase in free amino acids of beef during the postmortem was 3 μmol/g meat per day, especially large increases were in Ala, leu, Ser and Val.

The increase of amino acids in beef with increasing aging time has been reported due to the proteolysis of myofibrillar proteins, the action of calpains and cathepsins on major myofibrillar proteins, generating protein fragments and intermediate size polypeptides, furthermore polypeptides and peptides generate free amino acids (Toldra, 2006). Sarcoplasmic proteins are also degraded during the postmortem storage in beef and pork (Nishimura, 1998; Okumura *et al.,* 2004). The final protein degradation products, such as peptides and free amino acids, were thought to be caused by the action of endogenous proteinases, oligopeptidases and aminopeptidases C, H and P (Feidt *et al.*, 1996; Moya *et al*., 2001). Thus, from our results it could be concluded that muscle type and aging time had a large influence on the amounts of FAA content.

Effect of different Hanwoo muscle and aging period on nucleotide content

The effect of muscle on the nucleotides, included IMP, GMP, Hx and inosine during aging are shown in Table 2. The significant muscle effect was observed on IMP, Hx and inosine, in which the amount of Hx in the LD muscle was higher than that on the ST muscle. Similarly, Faustman and Cassens (1991) also reported that Hx content of the LD muscle was significantly higher than the *gluteus medius* (LM) muscle. The adenosone 5-triphosphate (ATP) concentration is usually approximately 5-8 μmol/g in resting muscle but rapidly drops within a few h postmortem by converting into adenosine 5-diphosphate (ADP) and adenosine 5-monophosphate (AMP). ADP and AMP act as intermediate compounds and both decrease to negligible values after 24-48 h postmortem (Aristoy and Toldra, 2009). The AMP is deaminased into IMP and this compound is progressively changed into inosine and Hx in the fresh meat after slaughter (Mateo *et al*., 1996; Nishimura *et al.,* 1988). However, the time and amount of reaching maximum or minimum in meat have also been reported varied depending on the many factors such as breed, slaughtering method heat treatments (Kavitha and Modi, 2007; Koga *et al*., 1987). Generally, the 5- ribonucleotides are

Table 2. Mean concentrations (μmol/g) of nucleotides in LD and ST muscles from Hanwoo beef during chiller aging

Nucleotides	*Longissimus dorsi*		*Semitendinosus*		SEM[1)]	F value		
	7 d	28 d	7 d	28 d		Muscle	Aging	Muscle*Aging
GMP	0.07	0.35	0.07	0.23	0.05	0.41	36.23***	0.87
IMP	4.89	4.01	4.68	3.14	0.27	3.81*	19.29***	1.44
Hx	2.16	2.35	1.12	1.60	0.14	38.45***	5.22*	1.03
Inosine	1.73	2.62	2.87	3.24	0.16	29.24***	14.98**	2.69

[1)]SEM: Standard error of mean.
*$p<0.05$; **$p<0.01$; ***$p<0.001$

present in larger amounts in meat and have an important contribution to meat flavor (Liu *et al*., 2007). In our study, the amount of IMP decreased continuously during the aging whereas the inosine and Hx increased (Table 2), indicating that the IMP conversion took place strongly during aging. The IMP is transformed into Hx and inosine by endogenous enzymes or by microbial activity, which may explain the opposite changes between IMP, Hx and inosine during aging. Liu *et al*. (2007) reported that the conversion reaction among nucleotides during processing, accounted for certain regular changes of nucleotides. It was reported that the Hx and inosine associated with a bitter taste of cooked pork (Tikk *et al.,* 2006). Overall, the results indicating the differences in nucleotides between the examined muscles during chiller aging periods is probably due to the difference in the levels and the conversion rate of the nucleotide/intermediates precursors (e.g., ATP) between the two muscles.

Comparison of taste-active compounds between Hanwoo and Angus beef breed

The mean values of individual free amino acids in 28 d-aged LD muscle between the two breeds are presented in Table 3. For the amino acids belong to the monosodium glutamte-like taste (MSG-like), it was observed that the amounts of Asn, Asp and Glu in Hanwoo beef were significantly higher than those in Angus beef. Amongst them, Glu has been often used as additive in processed foods aiming to enhance the umami taste (Fuke, 1994; Wu and Shiau, 2002). Furthermore, Hanwoo beef had significantly higher total amount of sweet amino acids, in that the Ala was the most abundant amino acid. The high concentration of the Ala consequently contributes to the sweet taste of the meat and meat products (Wu and Shiau, 2002). It was observed that Hanwoo beef had significantly higher total amount of bitter amino acids in present work. Chen and Zhang (2007) reported that the amino acids with the hydrophobic side chains (Arg, His, Lys, Leu and etc) usually have an unpleasant bitter taste. By using the statistic classification model for our study, the total amounts of good tasting amino acids (e.g., MSG-like and sweet) in Hanwoo beef were confirmed to be larger than those in Angus beef (Fig. 1). No differences in the total amount of sulphur-containing amino acids however, the amount of Cys was significantly higher in Hanwoo beef (1.34 vs. 0.27). The amino acids containing a sulphur atom have a

Table 3. Free amino acids content (μmol/g) of 28 d-aged *longissimus dorsi* muscle from Hanwoo and Angus beef breed

Amino acids	Hanwoo	Angus	SEM[1)]	F value
Aspartic acid (Asp)	0.57	0.41	0.04	7.54*
Glutamic acis (Glu)	1.99	1.27	0.23	4.91*
Asparagine (Asn)	0.65	0.32	0.03	46.6***
Glutamine (Gln)	3.37	3.88	0.49	0.52
Total (MSG-like)[2)]	6.58	5.88	0.62	0.41
Alanine (Ala)	5.38	2.79	0.46	15.9**
Glycine (Gly)	1.89	0.45	0.15	50.3***
Serine (Ser)	1.76	1.08	0.12	16.7***
Theonine (Thr)	0.7	2.39	0.09	167.5***
Proline (Pro)	0.74	1.05	0.06	11.5**
Total (Sweet)	10.47	7.76	0.67	8.18*
Arganine (Arg)	0.56	0.51	0.09	0.14
Histidine (His)	ND	0.56	0.04	0
Lysine (Lys)	1.0	0.82	0.06	1.71
Tyrosine (Tyr)	0.18	0.25	0.03	2.34
Tryptophan (Trp)	1.49	1.2	0.16	2.5
Phenylalanine (Phe)	0.86	0.49	0.51	2.7
Isoleucine (Ile)	2.01	1.43	0.13	1.09
Leucine (Leu)	1.57	1.56	0.01	0.16
Valine (Val)	1.12	0.76	0.11	2.24
Total (Bitter)	8.79	7.58	0.85	10.6*
Cystine (Sys)	1.34	0.27	0.08	96.46***
Methionine (Met)	1.00	1.10	0.03	0.58
Total (Sulphur)	2.34	1.37	0.07	0.63
Total free amino acids (FAA)	28.17	22.59	0.09	4.5*

[1)]SEM: Standard error of mean. [2)]Monosodium glutamate-like taste. nd: not detected.
*p<0.05; **p<0.01; ***p<0.001

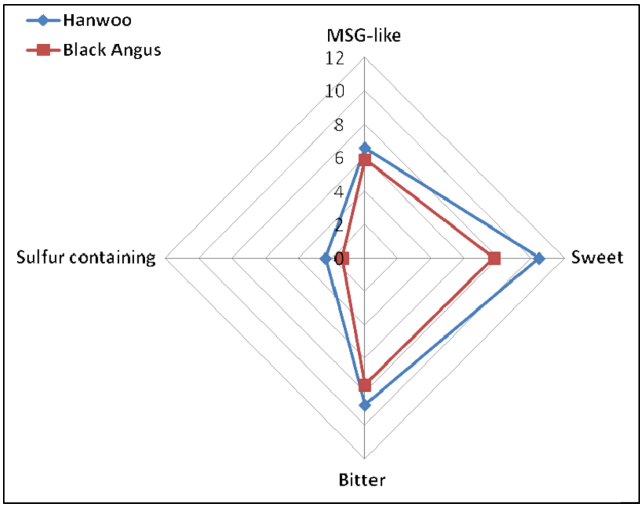

Fig. 1. Comparison of taste quality of 28 d-aged LD muscle from Hanwoo and Angus beef.

sulphury note (Chen and Zhang, 2007). On the other hand, these sulphur-containing amino acids are potent precursors of volatile compounds which possess the odor flavor of cooked meat. Koutsidis *et al.* (2008b) reported that the precursors of volatile sulfur-containing compounds are formed from sulfur-containing amino acids, which break down during the cooking of meat. Thus, from our results it is suggested that genetic (breed) may be one of the important factors affecting the FAAs content, and the results indicating the FAA differences between the two examined breeds is probably due to the differences in the proteolytic levels directly caused by the enzyme activity.

Mean concentrations of nucleotides in LD muscle from Hanwoo and Angus beef aged for 28 d are shown in Table 4. The GMP and Hx contents were significantly higher in Hanwoo beef than Angus beef, indicating that a greater conversion of intermediate compounds took place in Hanwoo beef. Earlier workers (Faustman and Cassens, 1991; Koutsidis *et al.,* 2008a) studied on other cattle breeds also found that the Hx content was affected by the examined breed. IMP has been widely used as a flavor enhancer to increase palatability, its found to contribute to the sensory attributes like brothy and meaty (Chen *et al*., 2004; Tikk *et al.,* 2006). The IMP contributes to the pleasant delicious taste and most to the umami taste by synergistic effect with MSG and GMP (Massa *et al.*, 2003). Chen *et al*. (2004) found that the umami taste score of chicken meat soup was obviously increased by adding small amounts of IMP (15 mg/g) together with monosodium glutamate (15 mg/g) compared with 200 mg/g of monosodium glutamate added alone. In the present study, the IMP was the most abundant nucleotide in both beef breeds (4.01 vs. 4.24) but no differences were observed between the two breeds (p>0.05). From our study results it is suggested breed might also be an important factor affecting the nu- cleotide content particularly GMP and Hx which subsequently may impart the taste quality.

Table 4. Mean concentrations (μmol/g) of nucleotides of 28 d-aged *longissimus dorsi* muscle from Hanwoo and Angus breeds

Nucleotides	Hanwoo	Angus	SEM[1)]	F value
GMP	0.41	0.08	0.06	15.16***
IMP	4.01	4.24	0.26	0.41
Hx	2.35	1.45	0.13	23.92***
Inosine	2.62	2.84	0.19	0.66

[1)]SEM: Standard error of mean.
**p<0.01; ***p<0.001.

Conclusions

Current results revealed that the variations in free amino acids and nucleotides are great between different muscle type, cattle breed and aging time, which are likely associated different tastes between various sources of beef. Hanwoo beef had higher amounts of MSG-like and sweet amino acids than the imported Angus beef. The results likely mirror the preference of Korean consumers to Hanwoo beef.

Acknowledgements

It should be acknowledged that this work was supported by a grant from the FTA issue programs No. PJ907055 and PJ008525, Rural Development Administration, Republic of Korea.

References

1. Aristoy, M. C. and Toldra, F. (1991) Deproteinization technique for HPLC amino acid analysis in fresh pork muscle and dry cured ham. *J. Agri. Food Chem*. **39**, 1792-1975.
2. Aristoy, M. C. and Toldra, F. (2009) Nucleotides and its derived compounds. In: Handbook of Muscle Foods Analysis, Nollet, L. M. L., Aristoy, M-C, Toldra, F. (eds). Toyler and Francis Group, LLC, pp. 279-298.
3. Chen, J. L., Wen, J., Wang, S. B., Zhao, G. P., Zheng, M. Q., and Yang, N. (2004) Sensory evaluation for umami taste of inosine-5-monophosphate. *China Poult*. **8**, 104-106.
4. Chen, D. W. and Zhang, M. (2007) Non-volatile taste active compounds in the meat of Chinese mitten crab (*Eriocheir sinensis*). *Food Chem*. **104**, 1200-1205.
5. Faustman, C. and Cassens, R. G. (1991) The effect of cattle breed and muscle type on discoloration and various bio-

chemical parameters in fresh beef. *J. Anim. Sci*. **69,** 184-193.
6. Feidt, C., Petit, A., Bruas-Reignier, F., and Brun-Bellit, J. (1996) Release of free amino acids during aging in bovine meat. *Meat Sci.* **44**, 19-25.
7. Flores, M., Alasnier, C., Aristoy, M. C., Navarro, J. L., Gandemer, G., and Toldra, F. (1996) Activity of aminopeptidase and lipolytic enzymes in five skeletal muscles with various oxidative pattern. *J. Sci. Food Agric.* **70**, 127-130.
8. Flores, M., Armero, E., Aristoy, M., and Toldra, F. (1999) Sensory characteristics of cooked pork loin affected by nucleotide content and post mortem meat quality. *Meat Sci*. **51**, 53-59.
9. Fuke, S. (1994) Taste-active components of seafood's with special reference to umami substances. In: Chemistry, processing technology and quality. Shahidi, F., and Botta, J. R. (eds). Blackie Academic and Professional. Glasgow, UK, pp.115-139.
10. Gerard, K. W., Hipkiss, A. R., and Schneider, D. L. (1988) Degradation of intracellular protein in muscle. *J. Biol. Chem.* **263***,* 18886-18890.
11. Hwang, Y. H., Kim, G. D., Jeong, J. Y., Hur, S. J., and Joo, S. T. (2010) The relationship between muscle fiber characteristics and meat quality traits of high marbled Hanwoo steers. *Meat Sci*. **86**, 456-461.
12. Jo, C., Cho, S. H., Chang, J., and Nam, K. C. (2012) Keys to production and processing of Hanwoo beef: A perspective of tradition and science. *Anim. Front.* ***2***, 32-38.
13. Kato, H., Rhue, MR., and Nishimura, T. (1989) Role of free amino acids and peptides in food taste. In: Flavor chemistry. Teranishi, R., Buttery, R. G., and Shahidi, F (Eds). Trends and Development, pp. 158-174.
14. Kavitha, S. and Modi, V. K. (2007) Effect of water activity and temperature on degradation of 5'-inosine monophosphate in a meat model system. *LWT-Food Sci Tech*. **40**, 1280-1286.
15. Koga, K., Fukunaga, T., and Kawagoe, S. (1987) Free amino acids, carnosine and 5'-inosinic acid contents in the beef loin and beef round. *Met. Fac. Agr. Kagoshima Univ.* **23**, 121-129.
16. Kim, Y., Puangsumalee, P., Barrett, D., Haseltine, C., and Warr, S. (2009) Korean beef market: Developments and prospects, Australian Bureu of Agricultural and Resources Economics (ABARE) research report.
17. Koutsidis, G., Elmore, J. S., Oruna-Concha, M. J., Campo, M. M., Wood, J. D., and Mottram, D. S. (2008a) Water-soluble precursors of beef flavor: I. Effect of diet and breed. *Meat Sci*. **79**, 124–130.
18. Koutsidis, G., Elmore, J. S., Oruna-Concha, M. J., Campo, M. M., Wood, J. D., and Mottram, D.S. (2008b) Water-soluble precursors of beef flavor. Part II: Effect of post-mortem conditioning. *Meat Sci*. **79**, 270–277.
19. Liu, Y., Xu, X. I., and Zhou, G. (2007) Changes in taste compounds of duck during processing. *Food Chem*. **102**, 22-26.
20. Massa, A. E. Paredi, M. E., and Crupkin, M. (2003) A chemical assessment of freshness in stored adductor muscle from scallops. *Braz. J. Chem. Eng.* **20**, 147-152.
21. Mateo, J., Domeguez, M., Aguirrezabal, M. M., and Zumalacarregui, J. M. (1996) Taste compound in Chorizo and their changes during ripening. *Meat Sci*. **44**, 245-254.
22. Mottram, D. S. (1994) Some aspects of the chemistry of meat flavor. In: The Flavor of Meat and Meat Products. Shahidi, F. (ed) Blackie, Glasgow, pp. 210-230.
23. Moya, V.J., Flores. M., Aristoy, M-C., and Toldra, F. (2001) Pork meat quality affects peptide and amino acid profiles during the aging process. *Meat Sci*. **58**, 197-206.
24. National Livestock Cooperatives Federation (NLCF). (2004) Korean carcass grading standard. Seoul: National Livestock Cooperatives Federation.
25. Nishimura, T., Rhue, M. R., Okitani, A., and Kato, H. (1988) Components contributing to the improvement of meat taste during storage. *Agric. Biol. Chem*. **52**, 2323-2330.
26. Nishimura, T. (1998) Mechanism involved in the improvement of meat taste during postmortem aging; review. *Food Sci. Technol. Int*. **4**, 241-249.
27. Nishimura, T. and Kato, H. (1988) Taste of free amino acids and peptides. *Food Rev. Int*. **4**, 175-194.
28. Okumura, T., Yamada, R., and Nishimura, T (2004) Sourness-suppressing peptides in cooked pork loins. *Biosci. Biotechnol. Biochem*. **68**, 1657-1667.
29. Robbins, K., Jensen, J., Ryan, K.J., Homco-Ryan, C., McKeith, F.K., and Brewer, M. S. (2003) Consumer's attitudes towards beef and acceptability of enhanced beef. *Meat Sci.* ***65****, 721-729.*
30. SAS (2007) SAS/STAT Software for PC. Release 9.0, SAS Institute Inc., Cary, NC, USA.
31. Sasaki, K., Motoyama, M., and Mitsumoto, M. (2007) Changes in the amounts of water-soluble umami-related substances in porcine *longissimus* and *biceps femoris* muscles during moist heat cooking. *Meat Sci*. **77**, 167–172.
32. Savell, J. W., Branson, R. E., Cross, H. R., Stiffler, D. M., Wise, J. W., Griffin, D. B., and Smith, G. C. (1987) National consumer retail beef study: palatability evaluations of beef loin steaks that differed in marbling. *J. Food Sci.* **52***,* 517–519.
33. Tikk, M., Tikk, K., Trngren, M. A., Meinert, L., Aaslyng, M. D., Karlsson, A. H., and Andersen, H. J. (2006) Development of inosine monophosphate and its degradation products during aging of pork of different qualities in relation to basic taste and retronasal flavor perception of the meat. *J. Agric. Food Chem*. **54**, 7769-7777.
34. Toldra, F. (2006) The role of muscle enzymes indry-cured meat products with different drying conditions. *Trends Food Sci. Tech*. **17**, 164-168.
35. Woodward, C. and Henderson, J. W. (2007) High-speed amino acid analysis on 1.8ìm Reversed-Phase (RP) columns. Agilent technologies, Pharmaceuticals and Foods, pp. 1-13.
36. Wu, H. C. and Shiau, C. Y. (2002) Proximate composition, free amino acids and peptides contents in commercial chicken and other meat essences. *J. Food Drug Anal*. **10**, 170-177.

(Received 2013.4.1/Revised 2013.8.7/Accepted 2013.8.12)