

ORIGINAL ARTICLE

Comparison of feeding systems: feed cost, palatability and environmental impact among hay-fattened beef, consistent grass-only-fed beef and conventional marbled beef in Wagyu (Japanese Black cattle)

Khounsaknalath SITHYPHONE,¹ Mitsuyasu YABE,² Hiroshi HORITA,³ Keisuke HAYASHI,¹ Tomiko FUMITA,¹ Yuji SHIOTSUKA,¹ Tetsuji ETOH,¹ Fumio EBARA,¹ Olavanh SAMADMANIVONG,¹ Jochen WEGNER⁴ and Takafumi GOTOH¹

¹Kuju Agriculture Research Center, Kyushu University, Oita, ²Department of Agricultural Resource Economics, Faculty of Agriculture, Kyushu University, Higashi, Fukuoka, ³Association des Disciples d'Auguste Escoffier du Japon, Tokyo, Minato, Japan; and ⁴Leibniz Institute for Farm Animal Biology, Dummerstorf, Germany

ABSTRACT

The objective of this article is to compare feed cost, palatability and environmental impacts among feeding systems of high concentrate (HC), high hay (HH) and grass-only-fed (Gof) groups. Feed cost was the sum of costs paid for feed intake times the price of feed per kilogram. Palatability was measured by a panel taste test using HH and Gof beef and analyzed for differences. Environmental impacts were calculated based on 1 kg of Japanese beef yield of CO₂ equivalents (eq) and animal end weights at each feeding stage. Results showed that the HH and Gof feeding systems could significantly reduce feed costs by approximately 60% and 78%, respectively, from the HC. In the panel taste test, 50% and 47.50% of panelists indicated that HH beef was 'extremely delicious' and 'acceptable,' respectively, while 15% indicated that Gof beef was 'extremely delicious'; 62.50% indicated that Gof beef was 'acceptable.' Environmental impacts of each feeding system in terms of CO₂ equivalents (eq) were 9.32, 6.10 and 2.04 tonnes of eq for the HC, HH and Gof, respectively. The HH was an economical system that produced moderate impacts on the environment and had impressive taste.

Key words: environmental impacts, feed cost, grass fattening, palatability, Wagyu.

INTRODUCTION

Compared to European cattle, Japanese Black cattle have good potential to accumulate intramuscular fat called 'Shimohuri' (Gotoh *et al.* 2009). In the Japanese beef market, marbled beef from Japanese Black is quite popular and expensive. However, in Japan, recent attention has focused on oil prices, food mileage and environmental issues (e.g. greenhouse gases, global warming). Japan annually imports a large amount of food and animal feed equal to approximately 58.9 million tonnes throughout the world. This is equivalent to 914 billion tonnes-kilometers (t-km), or 1.6 times the yearly shipment, in terms of food mileage (Nakata 2003). In 2007, more than 24 911 960 million tonnes of grain feed were imported to Japan, and 4 564 228 million tonnes were specifically for beef cattle (USDA 2009). The Japanese beef cattle industry is highly dependent on imported feed to produce domestic marbled beef. According to these

figures, beef production in general has high production costs, especially due to feed and labor costs. As a result, domestic beef can be more expensive than imported beef, making it unaffordable for consumers.

Nakata (2003) also reported that feed materials have been transported from many countries with an average of 15 000 km based on the distance between Tokyo (Japan) and Cape Town (South Africa). Feedstuff production and grain transportation consume fuel energy and emit harmful gases into the environment. Feedstuff is considered a source of environmental pollution associated with beef production systems. Moreover, cattle and their waste also create environmentally harmful gases that are distributed into their

Correspondence: Takafumi Gotoh, Kuju Agriculture Research Center, Kyushu University, Oita 878-0201, Japan. (Email: gotoh@farm.kyushu-u.ac.jp)
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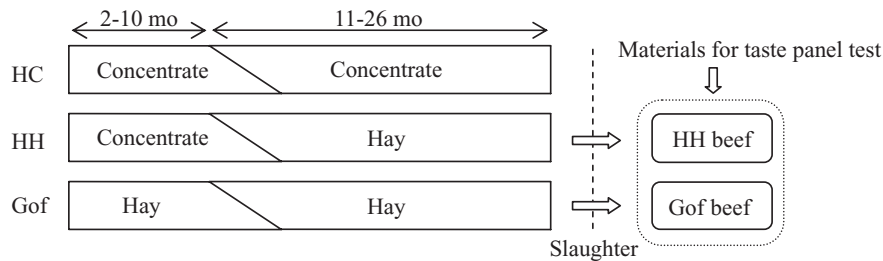


Figure 1 Feeding systems of conventional marbled beef (HC), hay fattening beef (HH), and consistent grass-only fed beef (Gof). In the panel taste test, we used HH and Gof beef.

surrounding environment. Many scientists have evaluated environmental impacts of livestock farming (Osada and Fukumoto 2001; Ogino *et al.* 2004, 2007). To address this issue, Hayashi *et al.* (2006) introduced a new feeding system by grazing cattle with forage in abandoned farmland to improve environmental preservation and to reduce the area of abandoned farmland. Moreover, several studies have been conducted aimed at controlling the quantity of concentrate composition in feed intake, and beef cattle have been given other feed to balance necessary nutritional and energy requirements (Realini *et al.* 2004; Nuernberg *et al.* 2005). Furthermore, French *et al.* (2001, 2003) reported that the beef carcass weight could increase even when animals are fattened by silage grass during the fattening period. In agreement with other researchers, Gotoh (2005, 2007, 2008) has suggested the implementation of new feeding systems to reduce the use of imported feedstuffs. In these new feeding systems, domestic grass resources are utilized that lessen the production of harmful gases in the environment through application of a metabolic imprinting¹ concept. Although cattle are fattened by only hay from 11 to 26 months of age, beef produced still contains approximately 10% intramuscular fat.

In rural areas of Japan, some farmers still feed hay to cattle for reproduction and graze them on pastures. However, few current studies focus on feeding systems that consistently use hay during the fattening period. It is critical to determine feeding systems that are beneficial for people related to the beef supply-and-demand chain. Therefore, the purpose of this study was to compare feed costs, beef taste (palatability) and CO₂ emissions associated with beef production systems

¹Alterations in fetal and early postnatal nutrition and endocrine status may result in developmental adaptations that permanently change the structure, physiology, and metabolism in the adult life of animals, is observed by nutritional treatment during not only fetus but also a neonatal early growth period. This phenomenon is referred to as “metabolic imprinting or metabolic programming” based on medical research regarding “the developmental origins of health and disease (DOHaD)”.

consisting of conventional marbled beef, hay-fattened beef and consistently grass-fed beef.

MATERIALS AND METHODS

Animals and feeding systems

Twenty Japanese Black Wagyu male calves were randomly selected and used for this study. These calves were from Japanese Black Wagyu beef cattle raised at the Kuju Agriculture Research Center, Oita, Japan. They were divided into three groups: a high concentrate fattening group (HC, $n = 6$); a hay fattening group that was fed hay after high concentrate feeding until 10 months of age (HH, $n = 7$); and a consistent grass-only feeding group that was only fed grass throughout full lives (Gof, $n = 7$). Calves from the three groups were fed highly nutritious milk and raised under the same program based on live weight and physical condition until they reached two months of age. From 2–10 months of age, calves in the HC and HH groups were given the same feeding program by using concentrate (more than 2.0% of body weight) until 10 months of age (Fig. 1). Animals in the Gof group were consistently fed only hay (the first harvest of Italian rye grass which contains the highest nutrition) from 2–26 months of age. From 11–26 months, steers in the HC were fattened using several fattening stuffs according to guidelines of the fattening program ‘Toyonokuni’ conducted by Oita Prefecture. This feeding system is a typical fattening program in Japan to produce marbled beef in which, during the early fattening stage of 11–15 months, the diet was composed of 73–50% roughages (hay, rice straw, alfalfa cube and Beer lees) and 27–50% concentrate. In the second stage of 16–19 months of age, the feed consisted of 40–30% roughages and 60–70% concentrate, and in the third stage of 20–28 months, the feed consisted of 16% roughages (rice straw) and 84% concentrate. The feed remaining was measured daily before adding new feed, and the quantity of feed provided was decreased when the amount of left-over feed was relatively high. In contrast, young steers in the HH group were only fed the same type of hay during the fattening period, and the quantity of feed intake was recorded daily. The average feed consumption and feed composition were determined by the total quantity of feed at the end of each feeding stage. All steers were sent to slaughter at 26 months of age.

Calculation of feed cost

In this study, the cost of hay acquired from local agricultural markets at 200 kg per roll was ¥5000 or ¥25 per kg. Hay in this study was grown and harvested at the research center

Table 1 Prices of animal feed diets in the local retail market

Animal feedstuffs	Price (¥/kg)	Animal feedstuffs	Price (¥/kg)
Pre-weaning feed	87.4	First formula feed	79.3
Post-weaning feed	101.1	Middle formula feed	80.3
Concentrate	74.8	Finishing formula feed	79.3
Hay	25.0	Jamboree	29.9
Rice straw	50.0	Hay cube	58.6
Wheat straw	37.5		

All prices were derived from orders and invoices between the research center and the local feed market in Oita Prefecture in 2007. The price included a handling and transportation charge. The hay price used in this study was based on purchases from the local market. In addition, hay was cultivated and processed at the research center. Therefore, the price represented the overall cost to produce hay, including labor, machinery, grass seed, fertilizer, maintenance, etc.

of the University farm. Other costs regarding machinery, labor and livestock stables were the same for all three groups. All animals were fed by the same person for similar durations. Also, this study was conducted in the same stable and with the same feeding methods with prepared feed (concentrate or hay). Therefore, we calculated only feed costs (FC) in the three groups and made comparisons among them. Feed cost was calculated based on prices of invoices and receipts from a local feed retailer in Oita Prefecture and the total amount of consumption in each feeding period (Table 1) is as follows:

$$FC = P_n \times V_n$$

where P = price of feed and V = volume of feed consumption in each stage.

$$FC = (P_{Pr-w} V_{Pr-w} + P_{Po-w} V_{Po-w} + P_{Con} V_{Con} + P_{Hay} V_{Hay} + P_{Ric} V_{Ric} + P_{Whe} V_{Whe} + P_{Fir} V_{Fir} + P_{Mid} V_{Mid} + P_{Fin} V_{Fin} + P_{Jam} V_{Jam} + P_{Hcu} V_{Hcu})$$

where Pr-w = Pre-weaning, Po-w = Post-weaning, Con = Concentrate, Ric = Rice straw, Whe = Wheat straw, Fir = First formula, Mid = Mid formula, Fin = Final formula, Jam = Jamboree and Hcu = Hay cube. The calculation was computed for individual animals and for groups, and the feed cost was then broken down into averages for each feeding stage per animal and per kilogram of animal body weight gain.

Beef preparation and panel taste test

The hay after high concentrate feeding and Gof beef groups were used in the panel taste test. In Japan's beef market, marbled beef is very popular. However, consumers prefer cheap imported beef because marbled beef is expensive. Commercial marbled beefs in Japan contain 20–60% of intramuscular fat (Horii *et al.* 2009). Therefore, to investigate the potential consumption of low-fat Wagyu beef, tasters' preferences were judged for HH (10% intramuscular fat) and Gof (6% intramuscular fat) beef. Rump was selected for roast beef because it is affordable and contains less fat. HH and Gof beef were kept in a freezer and stored in a fridge at the same temperature (15°C) prior to cooking.

The beef panel taste test was organized in Tokyo, on 23 January 2007. Roast beef was cooked for the taste test by a professional chef with 2 years of experience in Switzerland and France. Roast beef from HH and Gof beef was cooked with the same recipe and process.

Forty guests in Tokyo who attended a French restaurant were asked to taste the roast beef as panelists. The dishes were set on a table separated into two sections representing HH and Gof beef. The panelists were given a questionnaire, and the origin and feeding system of both beef types were explained. The questionnaire consisted of panelists' ages and gender and categories of taste (texture, flavor, juiciness, tenderness, tastiness and overall palatability). After tasting both dishes, the panelists were requested to grade taste based on three categories: distasteful, acceptable and extremely delicious.

Environmental impact of each feeding system

This study estimated environmental impacts regarding gas emission by the HC, HH and Gof feeding systems in three stages (2–10, 11–26 and 2–26 months of age). To evaluate environmental impacts, the calculation was focused on 2–26 months of age (whole system basis) and 11–26 months of age (the fattening stage). Ogino *et al.* (2004) reported the effect of different feeding lengths in the Japanese beef fattening system on environmental impact by a life circle assessment method. They indicated a shorter feeding length resulted in lower environmental impacts in all the environmental impact categories. Ogino *et al.* (2007) also evaluated environmental impacts of the Japanese beef cow-calf system by the life circle assessment method. They concluded shortening calving intervals by 1 month reduced environmental impacts by 5.7–5.8% in all the environmental impact categories examined, and increasing the number of calves per cow also reduced environmental impacts in all the categories, although the effects were smaller. Meanwhile, Osada and Fukumoto (2001) showed the development of a new dynamic chamber system for measuring harmful gas emissions from composting livestock waste. The measured values of those gases obtained by the Infrared Photoacoustic Detector (IPD, multi gas monitor type 1312, INNOVA, Copenhagen, Denmark) method and conventional method at the time of a composting examination of swine waste were measured, and the differences were only a few percent of the total emissions. These studies have shown the volume of CO₂ equivalents (eq) emitted into the environment that are associated with the beef production system and are based on the production of 1 kg of beef at the retail store. To calculate CO₂ emission by HC, HH and Gof feeding systems, secondary data of environmental impacts of Japanese beef production was derived from Ogino *et al.* (2004, 2007) (Table 2). The calculation relied on animal live weight at the time of

Table 2 Reference data concerning Japanese beef production system associated with environmental impacts

	Beef Yield (%)	CH ₄ (%)	CO ₂ emissions (kg of CO ₂ equivalents) [†]	Reference
EI _{11-26 mo} [‡]	40	48	32.3	Ogino <i>et al.</i> (2004)
EI _{2-26 mo} [§]	40		36.4	Ogino <i>et al.</i> (2007)

[†]Kilograms of CO₂ equivalents are based on a global warming potential (GWP) including CO₂ = 1, CH₄ = 29, H₂O = 296 of time zone horizon of 100 years (IPCC 2001) and SO₂ = 1, NO_x = 0.7, and NH₃ = 1.88 by Heijungs *et al.* (1992); [‡]Emission calculated only during fattening period from 11 to 26 months of age; [§]Emission calculated from nursery until end of fattening period from 2 to 26 months of age. EI: Environmental impact.

slaughter multiplied by 40% of beef yield available at retail shops.

HC feeding system:

$$EI_{226\text{ mo}} = \text{weight (kg)} \times 40\% \times 36.4 \text{ kg of CO}_2 \text{ eq.}$$

= environmental impacts (CO₂ emission) for the whole feeding system.

$$EI_{1126\text{ mo}} = \text{weight (kg)} \times 40\% \times 32.3 \text{ kg of CO}_2 \text{ eq.}$$

= environmental impacts (CO₂ emission) during the fattening period.

$$EI_{210\text{ mo}} = EI_{226\text{ mo}} - EI_{1126\text{ mo}}$$

HH feeding system:

$$EI_{226\text{ mo}} = \text{weight (kg)} \times 40\% \times 32.3 \text{ kg of CO}_2 \text{ eq.}$$

= environmental impacts (CO₂ emission) for the whole feeding system (32.3 kg of CO₂ eq was applied only in hay consumption).

$$EI_{1126\text{ mo}} = \text{weight (kg)} \times 40\% \times 48\% \times 32.3 \text{ kg of CO}_2 \text{ eq.}$$

= environmental impacts (CO₂ emission) during fattening period (48%² of CH₄ was applied only in hay consumption).

$$EI_{210\text{ mo}} = EI_{226\text{ mo}} - EI_{1126\text{ mo}}$$

Gof feeding system:

$$EI_{226\text{ mo}} = \text{weight (kg)} \times 40\% \times 48\% \times 32.3 \text{ kg of CO}_2 \text{ eq.}$$

= environmental impacts (CO₂ emission) for the whole feeding system (32.3 kg of CO₂ eq and 48% of CH₄ were applied only in hay consumption).

$$EI_{1126\text{ mo}} = \text{weight (kg)} \times 40\% \times 48\% \times 32.3 \text{ kg of CO}_2 \text{ eq.}$$

²CH₄ constitutes 48% of excreting gases from cattle when they are fed consistent silage dried grass 'hay' Ogino *et al.* (2004).

= environmental impacts (CO₂ emission) during fattening period (32.3 kg of CO₂ eq and 48% of CH₄ were applied only in hay consumption).

$$EI_{210\text{ mo}} = EI_{226\text{ mo}} - EI_{1126\text{ mo}}$$

Regarding units, CO₂ eq (carbon dioxide equivalent) has been known as an international standard of measurement that indicates the amount of different greenhouse gases (GHGs) which potentially cause global warming (IPCC 2001).

Statistical analysis

All data involving feed costs are presented for each feeding system, by feed cost per head and by 1 km of bodyweight gained. Means were compared by one-way analysis of variance (ANOVA) using the SPSS statistical software program (SPSS Inc. 2007). Frequency and descriptive analysis following methods in the SPSS statistics manual (2007) were used to define differences among responses from the taste panel questionnaires.

RESULTS

Feed cost

Animal growth and intake were different among the feeding systems in the final weight of each period. Namely, at 10 months of age, body weight was the highest in the HC (277 kg), followed by the HH (265 kg) and then the Gof (117 kg) groups ($P < 0.01$). There was a similar trend at 26 months, with the HC group having highest body weight (640 kg), followed by the HH (472 kg) and Gof (357 kg) groups ($P < 0.01$) (Table 3).

There were small differences between the HC and HH groups at 2–10 months in the quantity of feed intake (1 679 kg and 1 924 kg, respectively) and costs (¥96 832 and ¥103 053, respectively). In contrast, the amount of feed intake and cost of the Gof (1 301 kg and ¥32 530, respectively) were significantly lower than those of the HC and HH groups ($P < 0.01$). During the period of 11–26 months of age, feed intake and feed costs significantly differed among the three groups. They were the highest in the HC (feed intake: 5 126 kg, feed cost: ¥348 925), followed by the HH (feed intake: 3 219 kg, feed cost: ¥80 475) and were the smallest in the Gof (feed intake: 2 664 kg, feed

Table 3 Final body weight, total feed intake and total feed cost in HC, HH and Gof feeding systems during 2–10 and 11–26 months of age

	HC	HH	Gof
2–10 months of age			
Final body weight (kg)	277 ± 19 [†]	265 ± 18 [‡]	117 ± 13 [§]
Total feed intake (kg)	1679 ± 301 [‡]	1924 ± 154 [†]	1301 ± 138 [§]
Total feed cost (¥)	96 832 ± 17375 [‡]	103 053 ± 8245 [†]	32 530 ± 3459 [§]
11–26 months of age			
Final body weight (kg)	640 ± 47 [†]	472 ± 42 [‡]	357 ± 25 [§]
Total feed intake (kg)	5126 ± 492 [†]	3219 ± 421 [‡]	2664 ± 184 [§]
Total feed cost (¥)	348 925 ± 31 598 [†]	80 475 ± 15 036 [‡]	66 598 ± 4597 [§]

All data are means ± standard error. †,‡,§Different superscripts within rows indicate significant differences among groups ($P < 0.01$). HC, conventional marbled beef, $n = 6$; HH, high hay fattening beef, $n = 7$; Gof, consistent grass-only fed beef, $n = 7$.

cost: ¥66 598) groups ($P < 0.01$). As a result, the feed cost per head differed significantly ($P < 0.01$) among the HC (¥445 757), HH (¥183 528) and Gof (¥99 128) groups. On the other hand, the feed cost per kilogram of bodyweight gained was highest in the HC (¥731), followed by the HH (¥418) and then the Gof (¥ 306) groups ($P < 0.01$). Therefore, the most expensive feed cost was found in the HC group, HH was cheaper, and the cheapest was Gof.

Meat quality from taste panel test

Information regarding the number of family members, education, occupation, income, ethnicity and religion were excluded from the panel questionnaire due to customers' privacy restrictions. The HH and Gof beefs were used in this study because most people were familiar with the taste of commercial marbled beef (HC beef). The percentage of panelists' response for the taste of roast beef in HH and Gof groups is shown in Figure 2. Fifty-two percent of panelists were male residents of Tokyo and ranged in age from 20 to 70 years. The majority of panelists were between 30 and 60 years, with people in their 70s being the minority.

For the HH roast beef, more than 50% of panelists chose 'acceptable' for flavor, juiciness and tenderness, while less than 10% of the panelists chose 'distasteful' for flavor and juiciness. Almost 50% of panelists selected 'delicious' and approximately 45% of panelists chose 'acceptable' for texture and tastiness. The same patterns were observed for overall palatability.

For the Gof roast beef, nearly 60% of panelists chose 'acceptable' for all categories. For flavor and tenderness, 30% to 40% of panelists selected 'distasteful'. However, 37.5% of panelists marked 'extremely delicious' for texture. For overall palatability, the percentage of panelists that chose 'distasteful' (22.5%) was higher than those that chose 'extremely delicious' (15%).

When observing gender in detail, 52% of males estimated HH as 'extremely delicious' and 19% indicate this in Gof beef; 47% of females indicated this

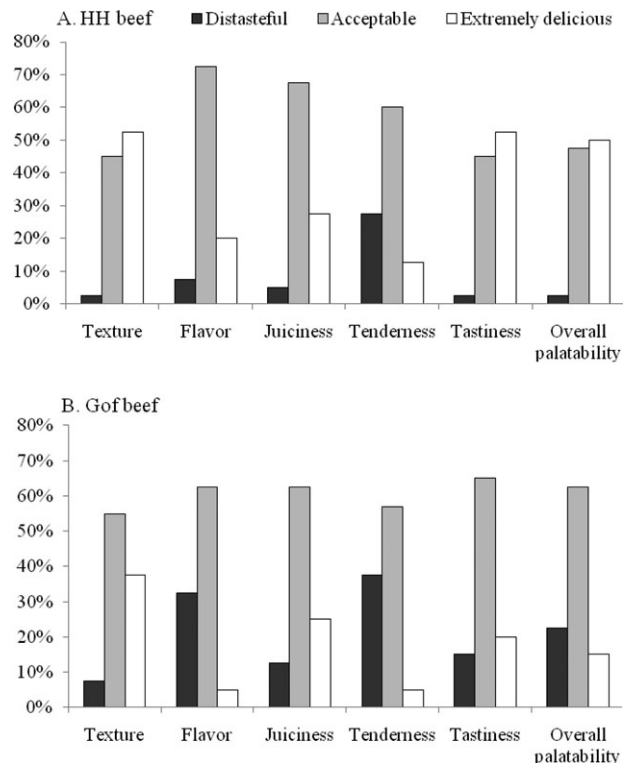


Figure 2 The percentage of panelists' response for the taste of roast beef in hay fattening beef (HH) and grass-only fed beef (Gof). Panelists: $n = 40$. Gender: male, 52.5%; female 47.5%. Age: 20–39, 40%; 40–59, 32.5%; 60–79, 27.5%.

with HH beef and 5% with Gof beef. Regarding generation, 60% of those in their 20s estimated HH beef as 'extremely delicious' and 0% for Gof beef; likewise those in their 30s were 55% and 27%, 40s 33% and 17%, 50s 57% and 14%, and 60s 56% and 11%, respectively. Those in their 70s did not estimate as 'extremely delicious' for either beef types (0%). All (100%) of those in their 70s estimated 'acceptable' for both beefs. This all suggests HH beef was preferable in each generation prior to the 70s and in each gender.

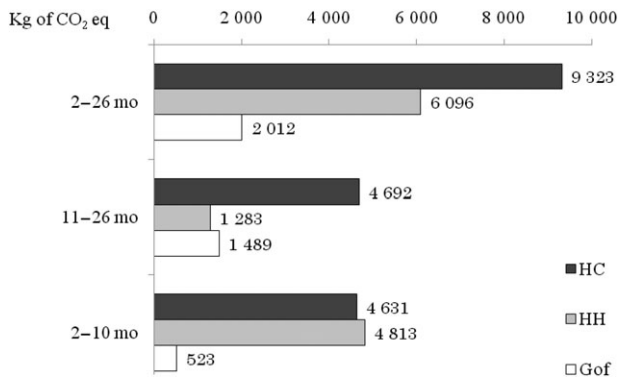


Figure 3 Volume of CO₂ emission/head associated with beef cattle production systems as part of environmental impact, including feed production, transportation and waste management, animal body and waste treatment by conventional marbled beef (HC), hay fattening beef (HH), and consistent grass-only fed beef (Gof) feeding system at 2–10, 11–16 and 2–26 months of age. These values were calculated by methods of Ogino *et al.* (2004, 2007).

Volume of CO₂ as environmental impacts by each feeding system

In this study, the environmental impacts associated with each beef production system were calculated for the 26 months of the study. Boundaries for assessing environmental impacts ranged from production of cattle feed to beef available at the retail shop and included the use of CO₂ equivalents (CO₂ eq) per 1 kg of beef as an indicator of impacts. The calculation included the three periods, namely 2–10, 11–26 and 2–26 months of age for the HC, HH and Gof groups (Fig. 3).

Environmental impacts in the HC group were 9 323 kg of CO₂ eq during 2–26 months of age (EI_{2-26 mo}), 4 692 kg of CO₂ eq during 11–26 months of age (EI_{11-26 mo}) and 4 631 kg of CO₂ eq during 2–10 months of age (EI_{2-10 mo}). Environmental impacts in the HH group during 2–26 months of age (EI_{2-26 mo}), 11–26 months of age (EI_{11-26 mo}) and 2–10 months of age (EI_{2-10 mo}) were 6 096 kg, 4 813 kg and 1 283 kg of CO₂ eq, respectively. Lastly, environmental impacts in the Gof group were 2 013 kg, 1 489 kg and 524 kg of CO₂ eq at 2–26 (EI_{2-26 mo}), 11–26 (EI_{11-26 mo}) and 2–10 months of age (EI_{2-10 mo}), respectively.

In general, the volume of CO₂ emissions was the largest in the HC group followed by the HH and Gof groups. This was especially pronounced during 11–26 months of age, with 4 631 kg of CO₂ eq in the HC, 1 283 kg of CO₂ eq in the HH and 524 kg of CO₂ eq in the Gof group.

DISCUSSION

In this study, the feed cost of the HC system was almost 60% higher than that of the HH system and

approximately 78% greater than the Gof system. Moreover, the HH system was 57% more efficient compared with the HC in terms of feed cost efficiency by bodyweight gain. In contrast, the Gof system was only 42% more efficient than the HC. In addition, bodyweight and growth were high in animals in the HC group, and the growth rate was slow and animal sizes were small in the Gof group. In other words, feed cost was inexpensive in the HH group, and these costs would be cheaper if farmers could efficiently produce hay with their own resources. Results indicate that the HH group had comparatively cheap production costs, and animals in this group had medium body weights among the three groups. Japanese Black Wagyu is a beef breed well-known for its superior composition of intramuscular fat, which is an indicator of marbling score and beef carcass grade (Zembayashi *et al.* 1995; Zembayashi & Nishimura 1996; Nishimura *et al.* 1999; Oka *et al.* 2002; Gotoh *et al.* 2009). However, many consumers have recently preferred less fatty beef due to health concerns, and they worry about obesity and other diseases. As a result, although animals in the HH group might have weighed less than those of the HC group, HH beef could maintain adequate intramuscular fat instead of producing an overabundance of fat as in HC beef or marbled beef (Horii *et al.* 2009).

In the panel taste test, three main aspects explain differences between roast beef cooked from HH and Gof beef. First, the percentage of acceptability in texture for both the HH and Gof roast beef was relatively high at 45% and 55%, respectively. This suggests that the appearance of the two beefs was similar after being cooked. Next, the percentage of flavor, juiciness and tenderness of both HH and Gof beef was approximately 60%. This indicates that HH beef still retained some characteristics of grass-fed beef. Finally, regarding tenderness, the percentage of panelists that chose 'distasteful' for HH beef was higher than other categories (27.5%), while 37.5% chose 'distasteful' for Gof beef. Harrison *et al.* (1978) and Nuernberg *et al.* (2005) indicated that beef produced from grazing or roughage could influence the degree of palatability. This could explain why HH beef had very few tough portions. Therefore, preference for HH beef in the taste test was high with regards to texture, tastiness and overall palatability; it was highly accepted by Japanese beef consumers in this study.

The HC, HH and Gof feeding systems produced different volumes of CO₂ emissions at 26 months on feed, 16 months in the fattening trial and 10 months after rearing, indicating differences in environmental impacts among feeding systems. Overall, the Gof was the least harmful system among the groups, with only 2.03 tonnes of CO₂ eq per head at 26 months of age. On the other hand, the HC feeding system had the highest environmental impacts with approximately

9.45 tonnes of CO₂ eq per head at 26 months of age. The HH system produced nearly 6.2 tonnes of CO₂ eq per head at 26 months, which was 30% less than the HC system. Although the HC system produced 3.05 tonnes less CO₂ eq per head than the HC system, several additional gases were produced with this system, including sulfur dioxide (SO₂), nitrous oxide (N₂O), nitrogen oxides (NO_x), ammonia (NH₃), methane (CH₄) and others (Osada & Fukumoto 2001; Ogino *et al.* 2004, 2007). SO₂, NO_x and NH₃ are especially harmful compared to the others.

IPCC (2001) reported that in some cases SO₂ has been connected with increases in respiratory illnesses and diseases related to breathing problems, as well as premature death in some countries. NO_x readily reacts with common organic chemicals, including ozone, to form a wide variety of toxic products. At very high concentrations of exposure, NH₃ can cause lung damage or death. While CH₄ is not toxic and has a net lifetime of 8.4 years in the atmosphere, carbon dioxide has a small effect over 100 years. However, it is flammable and explosive when mixed with compounds in the air.

In the HH system, CH₄ made up the bulk of gases by volume because this gas is mainly produced by feeding hay. This gas is more environmentally friendly than SO₂, NO_x and NH₃. In other words, cattle that ingested concentrate emitted a large volume of gasses, including toxic gasses, while cattle fed grass excreted less toxic gasses, but these cattle also emitted half the volume of CO₂ eq compared to the former cattle. In the end, the HH system is considered to be more environmentally friendly than the HC system.

The HH was a safe feeding system, with reasonably low production costs and less environmental impacts compared with the current marbled beef feeding system. Equally important was that many Japanese panelists in this study accepted HH beef and thought it was extremely delicious, even though it was similar in taste to grass-fed lean beef. In conclusion, the HH feeding system is a feeding system that can potentially decrease more than two-thirds of concentrate feed. In Japan, the HH system has several advantages over the current production system in terms of self-sufficiency, environmental impacts and providing a sustainable beef production system. This feeding system also benefits consumers, local farmers and beef traders. Thus, policymakers need to consider this system for its quality and classification prior to launching it in the domestic beef market. In brief, the HH feeding system has low costs, is environmentally friendly and produces delicious beef from cattle that are mainly fed grass resources locally produced in Japan. Future research should investigate how much local beef consumers are willing to pay for HH beef. This information can be useful for market development of this kind of beef.

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