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# Wagyu and the factors contributing to its beef quality: A Japanese industry overview

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ABSTRACT

Wagyu cattle are originated from native Japanese breeds, which have evolved by adapting to the unique climate and environment of Japan. Since the modern beef-eating culture started to flourish in Japan in the 1860s, Wagyu has been improved for higher quality beef to satisfy the taste preferences of Japanese consumers. The most noticeable characteristic of Wagyu beef is its intense marbling. The high intramuscular fat (IMF) content improves the texture, juiciness and thereby the overall palatability. In addition, the composition of the fat in Wagyu is considerably different from that in other beef breeds. Characteristic Wagyu beef aroma gives sweet and fatty sensation. Wagyu beef is also valued for its high traceability and uniformity guaranteed because of the nationwide standards for beef carcass and trading. Although Wagyu producers are currently facing issues regarding calf production, Wagyu beef is increasingly being exported to the global market and creating new market value as one of the world's most luxury food products.



## 1. Introduction

Wagyu ("*Wa*" meaning "Japanese" and "*gyu*" meaning "cattle") beef has swept across the niche market of luxury foods in Japan. After its registration by UNESCO as an intangible cultural heritage in 2013, Japanese cuisine has been gaining increasing popularity with gourmets around world. In accordance with this trend, Wagyu has been drawn into the world beef market, where it is setting new standards for quality in the assessment of gourmet beef products. Exports of Wagyu have been steadily and considerably increasing.

The intense marbling of Wagyu tends to be its most noticeable characteristic. However, in addition to the actual appearance of Wagyu beef, its unique production system, which has helped develop the high quality of Wagyu, is also remarkable. For example, the production process involves small-scale farming, a calf registration system, a beef traceability system, a nationwide unified grading system, and specialized meat cutting techniques.

With the objective of enhancing understanding of the true value of Wagyu, this article details its unique history, breeding, production process, patterns of consumption and quality. The names of prefectures and places referred to in this paper are shown in Fig. 1.

## 2. Background and definition of Wagyu

Although there are four Japanese beef breeds called "Wagyu", Japanese Black is the most popular breed. About 97% of Wagyu in Japan are Japanese Black (MAFF, Production, Marketing and Consumption Statistics Division, 2015).

Any beef claiming to be "Wagyu" must fulfill the following two conditions (MAFF, Committee on Indication of Meat, 2007):

(I) The cattle had to be the following Japanese pure and their cross breeds: Japanese Black (A), Japanese Brown (B), Japanese Shorthorn (C), Japanese Polled (D), crossbreeds between these four pure breeds (E), or crossbreeds between the E and A–E.
(II) The cattle had to be born and raised only in Japan.

Furthermore, evidence of the cattle must be verifiable by means of the calf registration system (refer to Section 4.4) and the beef traceability system (refer to Section 4.3). Only beef meeting these qualifications is officially licensed to use the public trademark, which certifies that it is from genuine and legitimate Wagyu (Fig. 2) (Japan Livestock Industry Association, 2015).

Wagyu is bred from native Japanese breeds. Native Wagyu breeds evolved by adapting to the unique climate and environment of Japan. Green forage is withered or covered with deep snow during winter, causing vitamin A deficiency in cattle. Since vitamin A is primarily stored in adipose tissues, natural and artificial selection of cattle having

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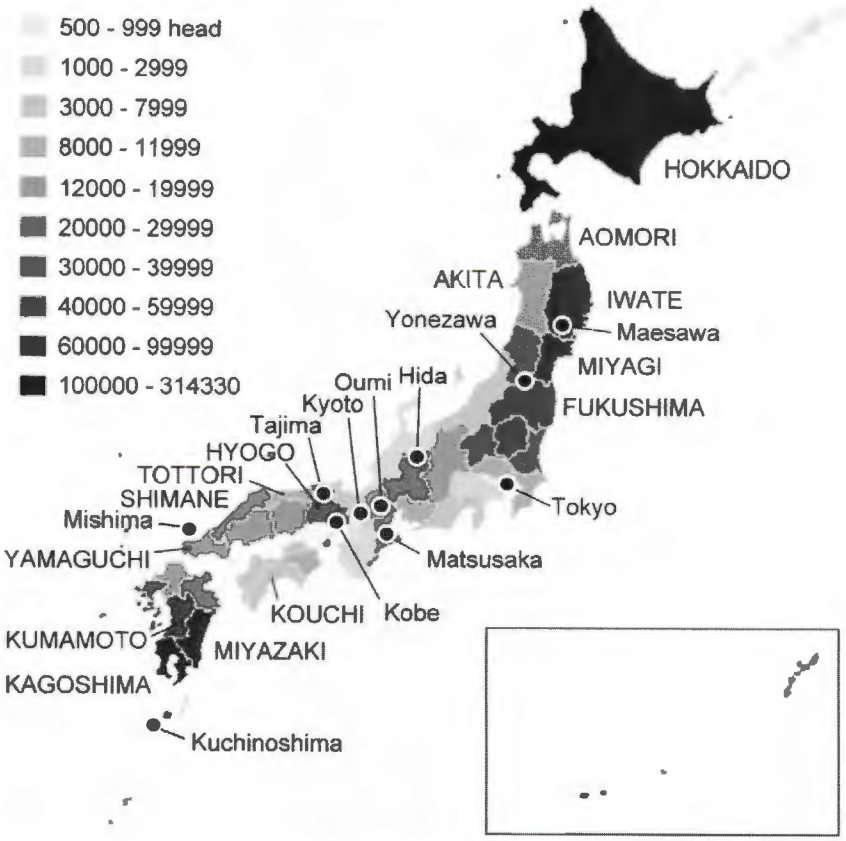


**Fig. 1.** Geographical names related to Wagyu. Prefecture names are in uppercase, and regional or city names are in lowercase. Prefectures colored with darker gray have larger Wagyu herd sizes.

a larger vitamin A storage with a larger mass of intramuscular fat is considered to happen (Hirooka, 2014).

The origin of native Japanese cattle is thought to be related to continental Chinese species, which were imported to Japan sometime around the Yayoi period (300 BCE to 300 CE) via the Korean Peninsula as draft cattle with rice farming culture (Nishinakagawa, Matsumoto, & Honda, 1991). Draft cattle were used for farm laboring and transporting heavy loads, and also for hackeries (cattle-drawn car) for nobles of the imperial family and aristocrats in Kyoto during the Heian period (794 to 1185 CE) (Fig. 3).

During the Edo period (1603 to 1868 CE), iron manufacturing was established in the Chugoku region (the western part of the island of Honshu). Domestic cattle with short but very strong legs were useful for transporting raw materials such as sand and charcoal from the


**Fig. 2.** Public mark for authentic Wagyu.

**Fig. 3.** A scene from *Tale of Genji* (written in the early 11th century), which was painted in the 17th century. Part of the Burke Albums, property of Mary Griggs Burke, reprinted from Wikipedia (https://commons.wikimedia.org/wiki/File:Ch42_nioumiya.jpg).

mountains (National Beef Cattle Advancement Fund Association, 2015). Also during this period on the Sanriku Coast of the Tohoku region (northeastern region of Japan), domestic cattle were brought in for transporting salt on their backs to the inland. Several kinds of domestic cattle with various physical distinctions were bred and raised for different purposes in accordance with their intended purpose.

Around the late Edo period (mid-19th century) in the Chugoku region, cattle were intentionally genetically improved in closed herds, similar to modern techniques for genetic improvements. It is notable that these techniques were applied years before knowledge of Mendel's law of heredity, which was proposed in 1865 and rediscovered in 1900. Several inbred strains based on dam lines were built up by breeders (wealthy farmers and cattle dealers) (Hirooka, 2014). These were referred to as "*Tsuru*", literally "vine plants". Before the Meiji era (pre-1868), Japanese cattle had a wide variation in color.

After the Meiji Restoration (post-1868), eating beef became part of a popular culture in Japan due to the westernization policy of the new government. To cope with this new demand for beef, the genetic improvement of local cattle breeds, which had previously only been used for labor, became conspicuously active in various regions of Japan. Several foreign breeds, including Shorthorn, Brown Swiss, Devon, Simmental and Ayrshire, were introduced to Japan during this period and crossbred with local Japanese breeds by local prefectural governments. Although the crossbreeds were larger and produced higher quantities of milk, they had inferior draft performance, and therefore none of the crossbreeding efforts were successful (Hirooka, 2014; Obata, Takeda, Satoh, & Wada, 1996). No further crossbreeding with foreign breeds was conducted after 1910. Nevertheless, because of the crossbreeding under local governments, the genetic diversity of the existing breeds was greatly expanded.

These crossbreeds were eventually inherited by "improved Japanese cattle," which were established in 1912. Through these processes, new breeds were fixed in 1944, and these have been acknowledged as the origin of the current Wagyu breeds (Japan Society of Meat Science and Technology, 2010) ("Japanese Shorthorn" was fixed in 1957). Around 1960, these dual-purpose breeds were indispensable for managing self-sufficient agriculture in Japan.

As agriculture using power tillers had become common among Japanese farmers after 1960s, the need for draft cattle diminished. The primary goal of breeding was to improve the quality of the beef. "Wagyu—can it still be a beef cattle?" was the subject of the first national competition for Wagyu meat production in 1966. Presently, Wagyu cattle for meat are being bred larger and heavier, but also with added value as a new and appealing source of beef.

The characteristics of Wagyu breeds, including body measurements, are shown in Table 1. All breeds are *Bos taurus* (Hirooka, 2014).

### 2.1. Japanese Black (Kuro-ge-wa-shu)

The Japanese Black is raised throughout Japan to produce high quality and luxury beef (refer to Sections 3.4 and 4.2). Japanese Black is representative of Wagyu and originates from the Chugoku region. A registration association for the breed was established in 1948 (Wagyu Registry Association, 2002), and since the 1950s, working together with domestic famers, public institutions have continuously succeeded in improving the quality of Japanese Black beef. Japanese Black has a brownish-black coat, gray skin, and black muzzles and hooves (Fig. 4a). Due to its meekness, it is an easy breed to tame. Japanese Black has a high degree of marbling and meat tenderness (refer to Section 4.2).

The fat content of the rib eye area is sometimes higher than 50%. The following blood strains in particular are used for breeding: *Tajima* strain (Hyogo Prefecture), *Ketaka* strain (Tottori Prefecture), and *Itozakura* strain (Shimane Prefecture). Currently, almost all of the Japanese Black in Japan have a pedigree comprising a combination of these three strains. The genetic variability of the economically important traits of Wagyu is thought to be similar to that in other beef breeds (Oyama, 2011). Another familiar name for Japanese Black is "*Kuro-ge*" or "*Kuro*".

### 2.2. Japanese Brown (Aka-ge-wa-shu)

The Japanese Brown is produced mainly in Kumamoto, Kochi, and Hokkaido Prefectures (MAFF, Production, Marketing and Consumption Statistics Division, 2015). There are two strains and their improvement processes were different. Japanese Brown has a caramel coat (Fig. 4b). They grow quickly, are docile in nature, utilize roughage effectively and have heat tolerance. The fat content of the rib eye area is about 12% or less (Japan Meat Information Service Center, 2013). Another familiar name for Japanese Brown is "*Aka-ushi*".

### 2.3. Japanese Shorthorn (Nihon-tankaku-shu)

The Japanese Shorthorn is raised mainly in the northern region of Japan (Iwate, Aomori, Akita, and Hokkaido Prefectures) (MAFF, Production, Marketing and Consumption Statistics Division, 2015). A breed in Iwate Prefecture named *Nambu-ushi* provided a base of strong limbs and hooves, as well as an aptitude for the northern climate of Japan. Japanese Shorthorn has a reddish-brown coat (Fig. 4c). Although their degree of marbling is inferior to that of Japanese Black, their high milk production and roughage utilization abilities allows Japanese Shorthorn to be well adapted to grazing.

### 2.4. Japanese Polled (Mukaku-wa-shu)

The Japanese Polled originated in Yamaguchi Prefecture. Compared with Japanese Black, Japanese Polled has a deeper black coat (Fig. 4d) and an inferior degree of marbling. At the first national competition for Wagyu meat production in 1966, Japanese Polled had a growing reputation as the future beef breed because of its ideal body measurements and rate of weight gain (National Beef Cattle Advancement Fund Association, 2015). However, head numbers are very limited at present, with only about 200 head currently bred and reared in Yamaguchi Prefecture.

The original Japanese native breeds, the first of the kind of Wagyu, can still be found. These are *Mishima ushi* (Mishima Island, Yamaguchi Prefecture) and *Kuchinoshima ushi* (Kuchinoshima Island, Kagoshima Prefecture) (Fig. 4e). Both native breeds are late maturing. *Mishima ushi* has been designated as a national natural treasure and is the only

**Table 1**
Characteristics of Wagyu breeds (MAFF, 2015; National Beef Cattle Advancement Fund Association, 2015).

| | Matured breeding cow | | | | Steer | | |
|---|---|---|---|---|---|---|---|
| | Weight (kg) | Withers height (cm) | Chest girth (cm) | Thurl width (cm) | Body weight (kg), (start of fattening) | Body weight (kg), (end of fattening) | Dairy gain (kg) |
| Japanese Black | 487 | 130 | 187 | 47 | 290 (9.0 months) | 755 (29 months) | 0.77 |
| Japanese Brown | 585 | 134 | 196 | 50 | 305 (9.5 months) | 750 (26 months) | 0.90 |
| Japanese Shorthorn | 585 | 133 | 199 | 49 | 245 (7.5 months) | 745 (26 months) | 0.87 |
| Japanese Polled | 580 | 128 | 205 | 51 | – | – | – |

breed that has not been crossbred with any foreign breeds. *Mishima ushi* has a black coat and good meat quality with exceptional marbling (Obata, 1994). The breed is physically very small, with a mean weight of 257 kg and a mean height of 113 cm in females, and 488 kg and 130 cm, respectively, in males (National Beef Cattle Advancement Fund Association, 2015).

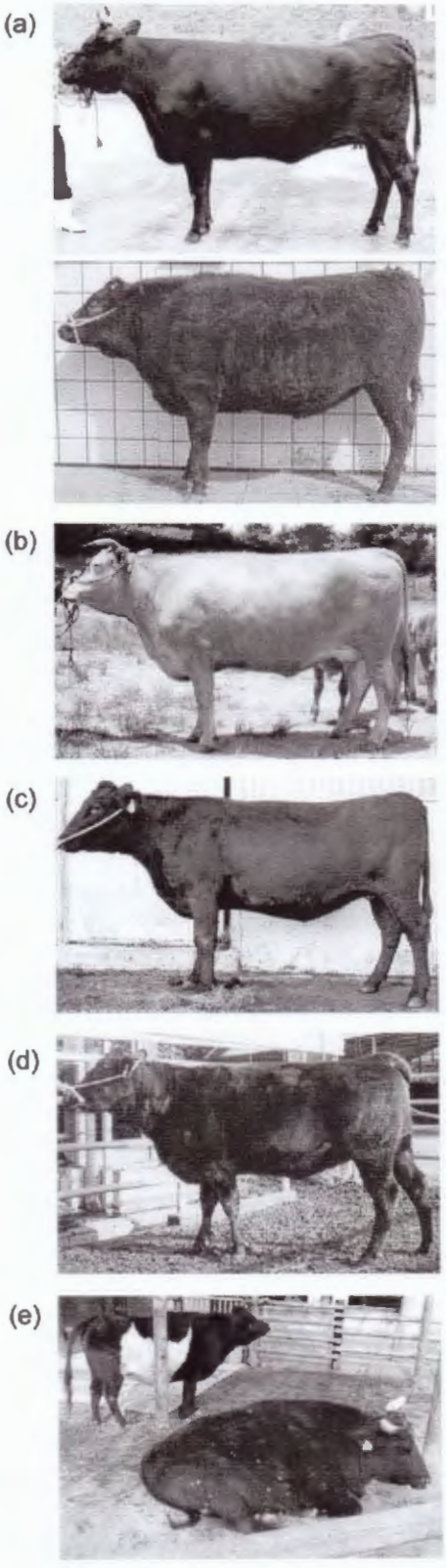


**Fig. 4.** The Wagyu breeds. (a) Japanese Black. Breeding cow (upper) and finishing steer (lower). Photo from National Beef Cattle Advancement Fund Association/Wagyu Registry Association. (b) Japanese Brown. *Kumamoto* strain, breeding cow. Photo from National Beef Cattle Advancement Fund Association/Agriculture Research Center of Komamoto Prefecture. (c) Japanese Shorthorn, breeding cow. Photo from National Beef Cattle Advancement Fund Association. (d) Japanese Polled, breeding cow. Photo from National Beef Cattle Advancement Fund Association/National Livestock Breeding Center. (e) *Mishima* cattle (front) and *Kuchinoshima* cattle (back) at Ueno Zoo (Tokyo). The anterior part of the body trunk is large, a characteristic feature of draft cattle.

## 3. Wagyu production

### 3.1. Production management

The habit of keeping cattle in small-scale farming (refer to Section 2) remains a common practice today. National average head count of beef cattle (all breeds) per farm was 44.6 in 2014 (MAFF, Production, Marketing and Consumption Statistics Division, 2015). Cattle farmers are currently making efforts to raise cattle in healthy and comfortable environments in accordance with guidelines such as "Proper-handling guidelines for raising and keeping industrial animals (Ministry of the Environment, 1987)", "Feeding management guidelines for beef cattle complementary with the concept of animal welfare (Japan Livestock Technology Association, 2011a)", and "Standards of rearing and hygiene management (MAFF, 2004)".

Through such practices, Japan is at a negligible risk for bovine spongiform encephalopathy (BSE) outbreaks and is free of foot-and-mouth disease (FMD) even though vaccination is not practiced, according to the Office International des Epizooties (OIE) Terrestrial Animal Health Code (January 2016 at the time of this writing). In addition, the use of growth hormones is forbidden in Japan.

Wagyu farmers are typically divided into two types: calf-production farmers and fattening farmers. This system is quite different from those common in other countries. Calf-production farmers feed breeding cow to produce calves and sell feeder cattle at auction. Breeding is mostly done by artificial insemination. There are two types of auction: "small markets" are for suckling calves 2 to 4 months of age, while "feeder cattle markets" are for those aged 6 to 12 months.

At these auctions, fattening farmers bid on a calf in consideration of its pedigree, and then fatten it with great care. Diverse fattening methods have been utilized based on market demand for various qualities of meat. On average, the slaughtering age is 29 months with a body weight of about 755 kg for Japanese Black steer (Table 2) (MAFF, 2015); however, some fattening methods are designed for extended periods of time, sometimes up to 50 months.

Fattened cattle can be marketed either live or as carcasses. For live animal marketing, buyers bid on cattle by predicting the carcass quality of each animal. For those marketed as carcasses, animals are slaughtered at a meat center and the carcasses are sold at auction where buyers bid on them based on quality and weight parameters. Carcasses are also sold by negotiation transactions. The carcass grading system will be described in more detail later (refer to Section 4.1).

### 3.2. Level of production

The head count of Wagyu in February 2014 was 1,716,000 (MAFF, Production, Marketing and Consumption Statistics Division, 2015), which represented 43% of the bovine head count in all of Japan and 64.8% of the total number of beef cattle. About 97% of Wagyu are Japanese Black (1,663,000 heads), which is the beef breed with the largest head count in Japan. The second largest head count of Wagyu (21,100 heads) is for Japanese Brown.

The number of Wagyu has recently experienced a serious decline. The number of slaughtering in 2014 was 507,422 with a decline of 4.2% from

**Table 2**
Carcass grading in Japan.

| | | Quality Grade | | | | |
|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 |
| Yield Grade | A | A5 | A4 | A3 | A2 | A1 |
| | B | B5 | B4 | B3 | B2 | B1 |
| | C | C5 | C4 | C3 | C2 | C1 |

2013 (MAFF, Production, Marketing and Consumption Statistics Division, 2014). This can be partially explained by the FMD (2010) that struck Miyazaki Prefecture, where more than 10% of the Wagyu in all of Japan were born. Furthermore, the Great East Japan Earthquake and Fukushima Daiichi Nuclear Power Station Disaster (2011) triggered the decision to quit farming. The number of beef cattle farmers at that time decreased by 11.9% in Miyazaki Prefecture and by 23.4% in Fukushima Prefecture (MAFF, Production, Marketing and Consumption Statistics Division, 2015). Furthermore, the aging of farmers has weakened the base of Wagyu breeding; this is expected to be an even larger problem in the future.

In response to these issues, carcass production has also decreased. From 2012 to 2014, production fell 3.9%, and was measured as 229,305.7 t in 2014 (MAFF, Production, Marketing and Consumption Statistics Division, 2014).

On a global scale, the carcass production of Wagyu is quite limited, equivalent to about 2% of beef carcass production in the United States (11,698,479 t) and Brazil (9,675,000 t), 4% of that in China (6,408,200 t), 8% of that in Argentina (2,822,000 t), 10% of that in Australia (2,317,766 t) and 17% of that in France (1,400,400) (2013 data) (FAO, 2015).

### 3.3. Production area

Although Wagyu is widely bred throughout Japan, there are particularly famous production areas. Wealthy farmers and cattle dealers in such regions have long bred their own local Wagyu strains (refer to Section 2), thereby forming individual beef production areas (Section 4.5).

The head count for Wagyu is especially high in Kagoshima, Miyazaki, and Hokkaido Prefectures (Fig. 1). Wagyu is bred in these provinces to take advantage of their rich environments.

### 3.4. Prices

The price of Wagyu beef is too expensive for daily consumption, even for Japanese consumers (average annual salary: 35,400 USD, 32,412 EUR) (National Tax Agency, 2015). Wagyu beef is typically reserved for special celebrations or feasts.

In November 2015, the average retail price for a cut of Japanese Black beef was 7650 JPY (65 USD, 60 EUR)/kg for shoulder; 7580 JPY (65 USD, 59 EUR)/kg for short plate brisket; 13,610 JPY (116 USD, 106 EUR)/kg for sirloin; and 7340 JPY (63 USD, 57 EUR)/kg for round (Agriculture and Livestock Industries Corporation, 2015). Wagyu beef with superior quality or exclusive and rare portions can be even more expensive. The retail price for tenderloin from *Matsusaka-ushi* (refer to Section 4.5) can be as high as 120,000 JPY (1020 USD, 940 EUR)/kg. Japanese consumers seldom eat large portions of beef or meat. Price of meat is therefore indicated with 100 g unit in retail stores.

As of November 2015, the wholesale price per 1 kg of A4 grade beef (refer to Section 4.1) from Japanese Black steer is as follows: 3315 JPY (28 USD, 26 EUR) for shoulder clod; 3833 JPY (33 USD, 30 EUR) for chuck roll; 2066 JPY (18 USD, 16 EUR) for brisket; 6665 JPY (57 USD, 52 EUR) for sirloin; and 3320 JPY (28 USD, 26 EUR) for top round (Agriculture and Livestock Industries Corporation, 2015). The average wholesale price of foie gras, a famous and expensive luxury food product from France, is 22–27 EUR/kg (with monthly variations) (Institut Technique de l'Aviculture, 2014), which is comparable to that of Wagyu.

In 2015, the wholesale price of Wagyu beef rose 10–15% from the previous year. This was due to a decline in the population of calves associated with the weakening of the calf production base (see Section 3.2). The number of Japanese Black calves was lower in 2014 than at any other time over the past 25 years (Fig. 5). Concurrently, the average price of Japanese Black calves has steadily risen over the past six years, and as of November 2015, was 693,000 JPY (5900 USD, 5500 EUR)/head (Agriculture and Livestock Industries Corporation, 2015).

## 4. Quality of Wagyu

### 4.1. Uniformity standards

A standard devised by the Japan Meat Grading Association and approved by the Director-General of the Agricultural Production Bureau of the Ministry of Agriculture, Forestry and Fisheries (MAFF) is serving as the nationwide unified transaction standard for Japanese beef. This standard guarantees that beef with the same grade anywhere in the country will have uniform quality. This standard is not a special criterion only for Wagyu, but common for all bovine breeds.

Carcass grading is performed primarily based on the surface of the 6th/7th rib cross section (Fig. 6). From the viewpoint of meat quality and yield, carcasses are evaluated by two indices (Yield Grade and Quality Grade) and graded into 15 categories (Table 2) (Japan Meat Grading Association, 2014).

Yield Grade is the ratio of meat to dressed carcass weight, and is classified into three grades, from A (above average yield of total cuts) to C (below average yield), according to measurements in the following four categories: thoracic longissimus muscle area; rib thickness; cold split carcass weight; and subcutaneous fat thickness (Japan Meat Grading Association, 2014). Quality Grade is categorized from 5 to 1 (larger values indicate higher quality), according to marbling, meat color and brightness, meat firmness and texture, and fat color, luster, and quality. Marbling is evaluated by according to a Beef Marbling Standard (BMS), which ranges from 1 to 12 (larger values indicate more abundant marbling). Recent advances in image analysis technology have led to the development of an accurate evaluating system (Kuchida et al., 2000; Maeda, Grose, Kato, & Kuchida, 2014) and the photographic reference of BMS (Japan Meat Grading Association, 2014). The national average BMS value for Japanese Black carcasses was 5.8 in 2014 (MAFF, 2015). Some average Quality Grade for as of 2015 were as follows: 3.7 for Japanese Black, 2.8 for Japanese Brown, and 2.0 for Japan Shorthorn (MAFF, 2015). The grade of the carcass shown in Fig. 6 is A5 with BMS No. 12.

Beef-cut trading standards have also been stipulated (Japan Meat Grading Association, 1988). The Japanese cut system is unique. Carcasses are dissected between and along muscles, in contrast to methods practiced in many countries, which make linear cuts. This system

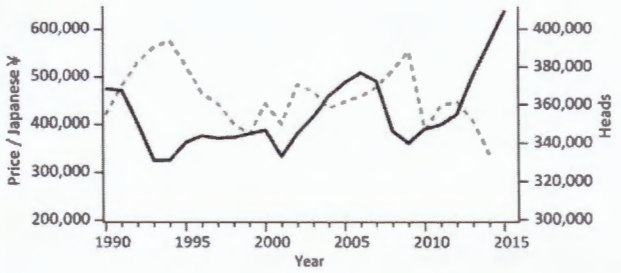


**Fig. 5.** Price (per head) and head count of Japanese Black feeder cattle. Solid line: price; dashed line: head count. The price for 2015 is the average from January to November. (Currency exchange rate as of January 2015 is 1 JPY = 0.00853 USD; 0.00781 EUR).

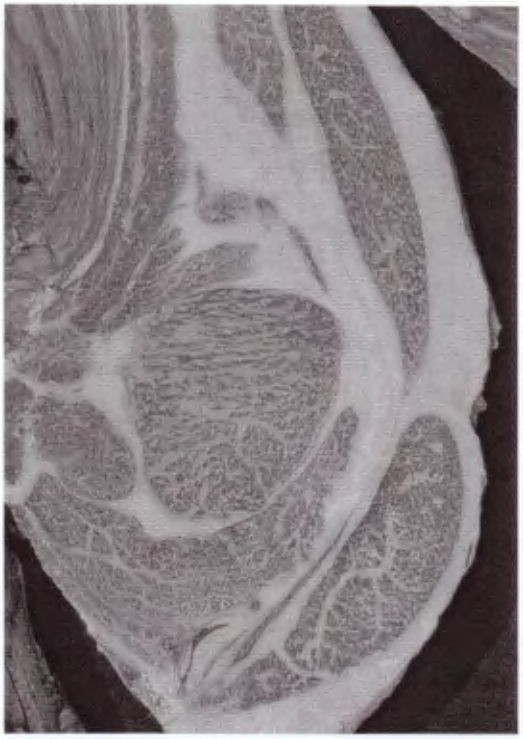

**Fig. 6.** Surface of 6th–7th rib section of a Japanese Black beef carcass. Photo: Courtesy of Mr. Chikada.

enables to produce relatively expensive products that require large area of a single muscle section, such as slices for *sukiyaki* and steak, and the amount of end-cuts is relatively less. Hard tissues such as tendons and fascia, which cannot be eaten unless cooked for a long period of time, are removed. The cuts are categorized according to the Quality Grade of the carcass.

### *4.2. Meat quality*

#### *4.2.1. Marbling*

The abundance of intramuscular fat (IMF, Fig. 6) in Japanese Black beef has attracted attention. In Japan, the value of carcasses is determined by a grading system (Section 4.1), which considers marbling as a significant determinant along with the consumers' strong appreciation of fine marbling. Since the liberalization of beef importation in 1991, marbling has been greatly emphasized to differentiate domestic beef from imported beef (Hirooka, 2014; Japan Livestock Technology Association, 2011b).

In the early 1980s, the content of IMF in the longissimus muscle at the 6th to 8th rib position of the Japanese Black cattle, which is considered as the highest quality category for abundance of marbling, was 31.7% (Ozutsumi, Ando, Ikeda, Nakai, & Chikuni, 1985). The IMF content at the 6th to 7th rib position in the carcasses with BMS No. 10 (the third highest category for abundance of marbling, refer to Section 4.1) was 26.1% in the early 1990s and 40% in 1998 (Cameron et al., 1994; Ueda et al., 2007). In 2015, it was over 40%, even in the carcasses with BMS No. 9 (Iida, Saitou, Kawamura, Yamaguchi & Nishimura, 2015).

High IMF content improves the texture and juiciness of beef and thereby the acceptability. Sensory quality evaluation has demonstrated that an increase in crude fat content (range 23.8%–48.6%) increases the tenderness, juiciness, and fattiness (Iida, Saitou, Kawamura, Yamaguchi, & Nishimura, 2015). Similarly, the longissimus muscle of Japanese Black having 25.8% IMF has greater juiciness than that of beef with 23.2% IMF, and the greater juiciness has increased the overall acceptability of beef (Okumura et al., 2007).

However, consumers do not necessarily favor excessive marbling. Iida et al. (2015) reported that an increase in the crude fat content reduces the crude protein content and slightly reduces the content of *umami* components (nucleic acid and glutamic acid). Increasing the IMF content up to approximately 36% enhanced the *umami* and beef flavor intensities and increased the overall evaluation score.

IMF content varies on the basis of time, finishing diet, and breed type. IMF increases with time in grain-fed and pasture-fed cattle, but the rate of increase in grain-fed cattle is faster than that in pasture-fed cattle (Smith, Gill, Lunt, & Brooks, 2009). Japanese Black steers that fed on a high-concentrate diet during the entire fattening period (from 10 to 30 months of age) show a higher expression of adipogenic transcription factors in the subcutaneous and intramuscular adipocytes than those fed on a high-roughage diet (Yamada & Nakanishi, 2012).

Regarding the effect of breed type on the IMF content, Duarte et al. (2013) investigated Wagyu (probably the Japanese Black) and Angus, which were managed under the same conditions, and showed that the IMF content and the numbers of preadipocytes and adipocytes were higher in Wagyu. Gotoh et al. (2009) investigated the IMF content in the longissimus muscle of a Japanese Black, German Angus, Belgian Blue, and Holstein Friesian (24 months old, reared under typical conditions) and found to be 23.3%, 4.4%, 0.6%, and 4.7%, respectively. The Japanese Black and the European cattle breeds do not differ in their mechanisms of postnatal fat accretion, which is a combination of increase in adipocyte number (hyperplasia) and adipocyte size (hypertrophy). However, they differ in their efficiency of accretion of IMF. For every 1% increase of IMF in the longissimus muscle, an increase of 3.0 kg of subcutaneous adipose tissue in Japanese Black, 4.3 kg in Holstein Friesian, 7.9 kg in German Angus, and 10.7 kg in Belgian Blue was observed (Gotoh et al., 2009). Perilipin 1 and adipose differentiation-related protein mRNA levels were higher in the IMF of the Japanese Black than Holstein. These results suggest that the advanced maturity of IMF cells in the Japanese Black and altered local conditions in the muscle influence the IMF accumulation and composition (Shirouchi et al., 2014).

The IMF content is not the only parameter that decides marbling quality. Marbling is called "*Shimo-furi*" in Japanese, literally means "frosting". Marbling with a fine appearance resembling frost is called "*Ko-zashi*" or "*Ko-sashi*" and highly valued in Japan, in contrast to "*Oo-zashi*" or "*Oo-sashi*", which means coarse marbling. The IMF deposits are found mainly between fiber bundles, resulting in the disorganization of the perimysium connective tissue, and therefore contributing the tenderness of beef (Nishimura, 2015; Sasaki, Motoyama, & Narita, 2012). Tenderness is perceived separately in "chewiness" and "hardness" by consumers (Sasaki et al., 2010; Sasaki et al., 2014); the histological difference in marbling may qualitatively affect the sensory of tenderness because of the difference in the tissue disorganization extent.

#### *4.2.2. Fatty acid composition*

The composition of fat in Wagyu is considerably different from that in other bovine breeds. Oleic acid concentration in the subcutaneous adipose tissue of Japanese Black, Hanwoo, Australian crossbred, Angus (corn-fed), Angus (hay-fed) and Angus (weaned) are 52.9%, 47.3%, 39.8%, 39.8%, 34.6% and 32.9%, respectively (Smith et al., 2006). There is the growing body of information that increased intake of oleic acid reduces risk factors for metabolic disease in humans. The concentration of oleic acid in beef adipose tissue is dependent on stearoyl-coenzyme A desaturase expression and activity, and Japanese Black are genetically disposed to produce more oleic acid (Smith et al., 2006). Very high heritability was reported for oleic acid in Japanese Black (Nogi, Honda, Murai, Okagaki & Oyama, 2011).

In addition to genetic factors, production conditions also affect the concentration of oleic acid. Higher levels of concentrated feed in the latter fattening period can lead to a higher concentration of

monounsaturated fatty acid in the subcutaneous adipose tissue of Japanese Black steer (Kimura, Kimura, Kosako, & Imura, 1996).

A high concentration of oleic acid is also associated with a low melting point of fat, and may be related to the overall palatability of the meat (Smith et al., 2006). A low melting point allows the fat to melt at mouth temperature. Efforts are currently being carried out in several brands of Wagyu to guarantee an oleic acid concentration of, for example, 55%, to add further value. The concentration of oleic acid can be evaluated rapidly and non-destructively using a portable near-infrared spectrometer (Irie, Oka, & Iwaki, 2003).

The melting point of the fat in Wagyu differs by terroir (Section 4.5). The melting point of intermuscular fat is 20–21 °C in *Kobe beef*, *Yonezawa-gyu*, and *Matsusaka-ushi*, and 25–26 °C in *Maesawa-gyu* and *Hida-gyu* (Sato et al., 1995). These differences are due not only to the genetic factors among the cattle strains in these terroirs, but also likely to the length of the fattening period practiced in each terroir. The melting point of the adipose tissue lipids of Japanese Black decreased from 35.5 °C in 14-month-old steers to 21.2 °C in 28-month-old steers (Mitsuhashi, Mitsumoto, Kitamura, Yamashita, & Ozawa, 1988). Feeding for longer period of time promotes a high concentration of oleic acid.

#### 4.2.3. Wagyu beef aroma

Japanese Black beef has a sweet and fatty aroma known as "Wagyu beef aroma", which is preferred by Japanese people. This aroma is almost absent immediately after slaughter, but is generated during storage under oxygen (Matsuishi, Fujimori, & Okitani, 2001). The optimum cooking temperature to generate this aroma is 80 °C. This is consistent with the optimum temperature of *sukiyaki* and *shabu-shabu*, which are typical Wagyu dishes.

One of the possible compounds contributing for this aroma is γ-nonalactone which has coconut- or peach-like aroma and a particularly high flavor dilution (FD) factor (Matsuishi et al., 2004). Lactones in beef play a role in the desirable deep fat-fried flavor and the high levels of lactones may mask the grassy flavor (Melton, 1990). The content of lactones increases through the oxidation of fat during storage (Watanabe, Imanari, Yonai, & Shiba, 2012). It is also reported that the formation of lactones associates with the composition of diet. Lactones are usually detected at higher amounts in the fat of cattle fed grain-based diets compared to grass-fed animals (Larick et al., 1987; Maruri & Larick, 1992).

In addition, alcohols and aldehydes with fatty aroma and diacetyl and acetoin with butter-like aroma would also contribute to the part of the fatty sensation of Wagyu beef aroma (Matsuishi et al., 2004).

Above described volatile compounds are the derivatives of fat. Wagyu beef aroma is therefore certainly attributed to the high fat content, and some extent, to the lipid oxidation during storage. It has been reported that the differences in fatty acid composition, adipose tissue location and beef production area have effects on beef aroma (Boylston et al., 1996; Melton, 1990; Migita et al., 2012): Their relations to the unique sweet and fatty Wagyu beef aroma remain to be elucidated.

### 4.3. Beef traceability system

In response to the first confirmed case of BSE in Japan in 2001 (as of 2016, Japan is considered to be "BSE risk-negligible" by OIE), the Law for Special Measures Concerning the Management and Relay of Information for Individual Identification of Cattle (Ordinance No. 72) was stipulated in 2003. To ensure reliability for the safety of beef, a Beef Traceability System was introduced to manage individual cattle information from birth to death or slaughter with Individual Identification Numbers (National Livestock Breeding Center, 2008). Individual Identification Numbers enable consumers to keep track of the following detailed information at all stages of distribution, from slaughter to consumption: Date of birth or import; sex; Individual Identification Number of the maternal parent; location (prefecture name) of the rearing facilities; start and end of breeding in the breeding facilities; date of slaughter, death, or export; breed of the cattle; for imported cattle, the name of the exporting country; and name and location of the abattoir where the cattle were slaughtered.

To ensure the validity of the Beef Traceability System, muscle tissue is sampled from each carcass and stored in the case that verification testing is required. When radioactive contamination became an issue after the Fukushima Daiichi Nuclear Disaster caused by the Great East Japan Earthquake and tsunami in 2011, arrangements for testing all slaughtered carcasses were made quickly, because these practices were already in place for BSE testing. Since the Nuclear Disaster, information about whether the said cattle was in the security area (20 km from the nuclear plant) one year after the accident has also been added to the search system (it should be noted that radioactive contamination of beef was found to be caused by the feeding of rice straw that had been left outside at the time of the accident; this issue has been addressed).

If diseased cattle or beef recalls come to light, it now is possible to know the current location of the cattle and their herd within 24 h by the use of the system. The Individual Identification Number has been utilized to confirm pedigree and terroir (refer to Section 4.5); this provides additional value. Smartphone applications have been developed that allow consumers to access the Beef Traceability System.

### 4.4. Calf registration

Wagyu calves are registered with registry associations soon after they are born. This registration system enables cattle farmers to trace ancestral lineage through three generations for each registered calf. In the registration inspections, inspectors register and confirm basic information for each individual calf, including muzzle pattern (pattern of wrinkles at the nose head), parentage (genotype testing possibly carried out), sex, name of breeders, date of copulation and birth, and any abnormalities (Wagyu Registry Association, 2002). When the calf meets certain eligibility requirements of Wagyu in the inspection, a "calf registration certificate" is issued; this certifies that the calf is Wagyu. These data not only serve as basic information of the above-mentioned Beef Traceability System, but also provide information on reproductive performance, such as calving intervals of the dam cow, for more efficient calf production.

### 4.5. Terroir

Rice has always been the major agricultural product in Japan. Wagyu have contributed significantly to Japanese agriculture by revalorizing rice straw, which is merely a by-product. Since rainfall in Japan is abundant (average: 1668 mm/year, about twice as much of the global average of 807 mm/year; Ministry of Land, Infrastructure, Transport and Tourism, 2015), and land mostly consists of steep mountains covered by forests, flat fields for grass and pasture are limited. Paddy rice fields had to be cultivated in the narrow valleys between mountains. The breeding of Wagyu cattle has been nurtured under the cultural background of Japan and this rice paddy farming system (also refer to Section 2). Since cattle have been indispensable for small-scale farming in Japan, the practice of treating cattle as members of the family is deeply rooted among Japanese farmers as a matter of habit. In addition, each individual cattle is raised with special and specific care.

#### 4.5.1. Kobe beef

Kobe beef is the beef of heifers or steers of Tajima-strain Japanese Black cattle (refer to Section 2) which are born in Hyogo Prefecture and only bred by designated breeder farmers in the prefecture for an average of 32 months (at least 28 months) (Kobe Beef Marketing and Distribution Promotion Association, 2016). Slaughtering is done at a meat center in the prefecture, and the carcass should have Yield Grade A or B (carcasses that meet these conditions are called *Tajima-gyu*), a

BMS No. of 6 or higher, a carcass weight of 470 kg or less, and have excellent firmness and texture. Both *Tajima-gyu* and *Kobe-beef* were registered as a Geographical Indication (GI) in 2015, according to the Act for Protection of Names of Designated Agricultural, Forestry and Fishery Products and Foodstuffs (GI Act) (MAFF, Food Industry Affairs Bureau, 2015). When Kobe Port was opened to foreigners for the first time in 1868, an Englishman at the time was amazed at the taste of *Tajima* beef, which was originally draft cattle. It was this appraisal that marked the beginning of *Kobe beef* (Kobe Beef Marketing and Distribution Promotion Association, 2016).

#### 4.5.2. Matsusaka-ushi

*Matsusaka-ushi* are Japanese Black heifers introduced in the area specifically around Matsusaka within 12 months of age and raised and fattened only in the area (Matsusakaushi Council, 2006). The herd size of *Matsusaka-ushi* is only about 11,000. Matsusaka beef, which can claim to be a "specialty," must be fattened for more than 900 days (slaughter at 38 month of age or older). A famous video exists in which a *Matsusaka-ushi* is given beer to drink in order to enhance its appetite, as well as massages for improved blood circulation.

#### 4.5.3. Omi-ushi

*Omi-ushi* has a distinguished history. It was once used as a tribute to the Tokugawa Shogunate in the name of curing agent during the Edo period (1603 to 1868 CE) (Omi Beef Production, Circulation Promotion Conference, 2013). *Omi-ushi* is the brand name for Japanese Black cattle having the longest fattening period in Shiga Prefecture. Among these cattle, only those that have been fattened at a designated farm, slaughtered and graded at designated meat centers, and graded B4 or higher are considered "authentic" *Omi-ushi*.

In addition to these terroirs, there are other famous cattle brands with geographical indications, such as *Maesawa-gyu*, *Yonezawa-gyu* and *Hida-gyu*.

## 5. Consumption of Wagyu

Consumption of Wagyu beef per capita in Japan is about 1 kg/year. Beef consumption of typical Japanese people is 5.9 kg/year (MAFF, 2014). Therefore, the average Japanese person consumes Wagyu about one out of every five to six times they eat beef. In the 1960s, which was a period of high economic growth in Japan, Wagyu dishes such as *sukiyaki* became a feast or sometimes a treat at work, and this was accompanied by the branding of Wagyu terroir. The premium feeling associated with Wagyu has become more prominent due to the increasing amount of relatively inexpensive imported beef, as well as increase in price resulting for reduced production.

Exports of Wagyu beef totaled 1251 t in 2014 (Japan Livestock Products Export Promotion Council, 2015), which corresponds to less than 1% of total production. Given the increasing popularity of Japanese cuisine around the world, the export of Wagyu beef as one of the main viands of Japanese cuisine is the focus of current policies; as a result, the amount of Wagyu beef exports increased by 41.6% from 2013 to 2014. However, Wagyu production is limited, and therefore so are exports. As of December 2014, 14 countries and regions were importing Wagyu beef, which was twice the number from April 2013. The top importers are, in descending order, Hong Kong (385 t), the United States (153 t), Singapore (123 t), Thailand (67 t), and the European Union (45 t).

## 6. Conclusion

In recent years, the exceptional quality of Wagyu beef has led to a steady increase in exports. As Wagyu beef becomes even more internationally known, its value, which is indispensable with the culture and environment of Japan, is being revealed and rediscovered. This review article hopefully leads to more detailed knowledge of the unique production system and meat quality of Wagyu and contributes to the proper understanding of the Japanese beef.

In accordance with Japan tradition, Wagyu beef is typically served as sizzling *sukiyaki* or *shabu-shabu* as opposed to steak because this allows one to enjoy the beauty of the marbling characteristic of sliced Wagyu beef at the table. When experiencing Japanese Wagyu cuisine, it is easy to recognize and be pleased with the distinctive marbling and unmistakable value of Wagyu beef. Please refer to http://www.jmi.or.jp/en/recipe/index.html for several English recipes.

## Conflict of interest

The authors declare no competing financial interests.

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