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REVIEW

On-Farm and Processing Factors Affecting Rabbit Carcass and Meat Quality Attributes

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Abstract Rabbit meat has high nutritional and dietetic characteristics, but its consumption rate is comparatively lower than other meat types. The nutritional profile of rabbit meat, by comparison with beef, pork, and poultry, is attributed to relatively higher proportions of *n*-3 fatty acids and low amounts of intramuscular fat, cholesterol, and sodium, indicating its consumption may provide health benefits to consumers. But, the quality attributes of rabbit meat can be originated from different factors such as genetics, environment, diet, rearing system, pre-, peri-, and post-slaughter conditions, and others. Different rabbit breeds and the anatomical location of muscles may also affect the nutritional profile and physicochemical properties of rabbit meat. However, adequate information about the effect of those two factors on rabbit meat is limited. Therefore, cumulative information on nutritional composition and carcass and meat quality attributes of rabbit meat in terms of different breeds and muscle types and associated factors is more important for the production and processing of rabbits. Moreover, some studies reported that rabbit meat proteins exhibited angiotensin-converting enzyme inhibitory characteristics and antioxidant properties. The aim of this review is to elucidate the determinants of rabbit meat quality of different breeds and its influencing factors. In addition, the proven biological activities of rabbit meat are introduced to ensure consumer satisfaction.

Keywords meat quality, quality determinants, factors affecting quality, biological activity, rabbit breeds

Introduction

The total production of rabbit meat worldwide in 2019 reached 883,936 tons. China is the largest rabbit meat-producing country in the world and produced 457,765 tons in 2019 and followed by North Korea (166,879 tons) and Egypt (44,893 tons; FAO, 2020). The worldwide per capita rabbit meat consumption was 0.242 kg in 2012 (Dalle Zotte, 2014). However, as rabbit meat consumption is not prevalent worldwide (Mancini et al., 2020), consumers are generally not aware of its high nutritional quality. Indeed, rabbit meat is characterized by high nutritional and dietetic properties, such as a high *n*-3/*n*-6 fatty acids ratio and low amounts of intramuscular fat, cholesterol, and sodium (Hernández et al., 2006; Wang et al., 2016). These excellent characteristics of rabbit meat would satisfy consumers who want to live healthily (Wang et al., 2020). Despite, consumers are reluctant to purchase rabbit meat because it is more expensive than poultry meat (Kallas and Gil, 2012) and has an undesirable typical wild flavor (Hoffman et al., 2004). Due to these reasons, the consumption rate of rabbit meat is still progressively declined (Cullere and Dalle Zotte, 2018). Nevertheless, the consumption rate of rabbit meat could be increased by developing value-added products, such as frozen, smoked, roasted, canned, cured, dried, sauce-picked products, and sausage-typed (Alekseeva et al., 2018; Yang and Li, 2010). Also, the processing would also mask the typical wild flavor of rabbit meat (Hoffman et al., 2004).

Animal husbandry is currently forced to increase meat production as to meet the demand of increasing world population (Ritchie et al., 2017). To meet consumer's demand, farmers adopt different management practices to increase meat production. The expenses rise when high inputs are invested. To overcome these challenges, it is more important to critically evaluate and analyze the factors associated with production and processing of farm animals. Rabbit meat industry is still under the transititional stage. Although, it has more potential to satisfy consumer's demand in terms of nutritional profile, but the production and processing sectors are not properly synchronized with the appropriate factors. During the past decades, researchers investigated several studies related to determinants of rabbit meat quality and influencing factors. Accordingly, the effect of genetic, age, environmental, management factors, pre-, peri-, and post-slaughter factors on nutritional characteristics, and carcass and meat quality attributes of rabbit were extensively performed (Apata et al., 2012; Cullere et al., 2018; Dalle Zotte et al., 2009; Paci et al., 2013; Simonová et al., 2020). However, few studies were only given importance to comparing different rabbit breeds and the anatomical location of muscles regardless nutritional composition and physicochemical properties (Dabbou et al., 2017; Martínez-Álvaro et al., 2018; Papadomichelakis et al., 2017; Perna et al., 2019; Wang et al., 2016). Moreover, commercial hybrid rabbits received more attention among reseachers as they have faster growth rate (Liste et al., 2009; Mancini et al., 2018; Mazzone et al., 2010). Nonetheless several studies revealed that other rabbit breeds had almost similar growth performance with high nutritional and meat quality profile than commercial hybrids (Chodová et al., 2014; D'Agata et al., 2009; Papadomichelakis et al., 2017). Therefore, comparison of meat quality of rabbit in terms of breeds will be worthy to understand the specific meat quality for rabbit deeply.

A few studies for bioactivity of rabbit meat was conducted (Chen et al., 2021; Chen et al., 2022). Rabbit meat proteins are identified with health benefits, such as angiotensin-converting enzyme (ACE) inhibitory characteristics and antioxidant properties (Chen et al., 2021; Permadi et al., 2019). Further, the fatty acid profile of different rabbit breeds and muscle types had excellent nutritional values which helps to prevent some health issues (Dabbou et al., 2017; Papadomichelakis et al., 2017). However, since these researches are still in their infancy, reviewing the study of functionality for rabbits will be worthy positively increasing the consumption of rabbit meat. Therefore, this manuscript reviews the characteristics of rabbit meat and the parameters associated with the meat quality from different breeds. In addition, some recently reported biological activities of rabbit meat are also discussed.

Characteristics of Rabbit Meat by Breeds and Anatomical Location of Muscles

Physicochemical properties

The physicochemical properties of different rabbit breeds were summarized and represented in Table 1. The nutritional composition, including the moisture, crude protein, crude fat, and ash contents of different rabbit breeds were ranging from 62.10%–75.60%, 20.0%–26.18%, 0.44%–6.56%, and 0.67%–1.57%, respectively. Compared with beef, the moisture and protein contents are almost similar (73.87%–77.9% and 20.0%–22.87% respectively; Muchenje et al., 2008). Moreover, the

Table 1. Physicochemical properties of different rabbit breeds

Breed	Moisture	CP%	CF%	Ash%	CIE L*	CIE a*	CIE b*	pH	References
Pannon White rabbit	75.00	21.97–22.33	1.50–1.53	0.67–1.00	46.91–51.83	0.63–0.76	6.29–8.10	5.57–5.60	Simonová et al., 2020
New Zealand White	72.10–75.24	20.0–25.08	0.44–6.56	1.12–1.57	46.09–63.71	–1.07–6.90	0.34–0.67	5.40–5.75	Dal Bosco et al., 2012; Liu et al., 2012; Menchetti et al., 2020; Perna et al., 2019
New Zealand White×California	NR	NR	NR	NR	45.69–53.54	3.23–14.88	1.36–5.81	6.02–6.08	Secci et al., 2019; Secci et al., 2020
Grimaud rabbits	62.10–75.11	21.50–22.97	0.87–1.03	1.21–1.25	50.60–54.04	–0.15–5.59	–0.41–6.04	5.38–6.23	Dabbou et al., 2017; Koné et al., 2016; Koné et al., 2019
Chinese rabbits	NR	NR	NR	NR	42.13–58.10	6.85–16.81	–15.24–0.54	6.21–6.27	Jia et al., 2017
Vienna Blue	NR	NR	NR	NR	53.2–58.2	2.87–3.76	–0.65–2.00	5.69–5.85	Dalle Zotte et al., 2016
Burgundy Fawn	NR	NR	NR	NR	53.4–58.6	2.62–4.10	–0.55–2.48	5.72–5.82	Dalle Zotte et al., 2016
Hyla	NR	NR	NR	NR	59.96–63.19	3.99–4.09	4.88–6.20	6.56	Wang et al., 2016
Champagne	NR	NR	NR	NR	59.31–61.87	4.04–4.63	6.66–6.75	6.48	Wang et al., 2016
Tianfu Black	NR	NR	NR	NR	58.54–61.29	5.10–5.46	4.64–5.20	6.67	Wang et al., 2016
Commercial hybrid	NR	NR	NR	NR	56.52–62.57	1.04–2.85	1.64–4.05	5.62–5.88	Liste et al., 2009; Mancini et al., 2018; Mazzone et al., 2010
Slow-growing rabbits	74.33–75.61	22.16–23.03	1.04–1.51	1.04–1.51	51.40–58.30	1.60–4.00	1.50–3.40	5.70–6.00	Paci et al., 2013
Local population	NR	NR	NR	NR	59.09	3.25	3.78	5.59	Paci et al., 2012
Grey coloured local rabbits	74.45–75.12	22.57–22.94	1.12–1.40	1.20–1.21	53.01–59.15	2.08–2.79	1.63–2.28	5.70–5.92	D'Agata et al., 2009
Spanish rabbit	73.10–75.60	21.00–21.30	1.90–3.90	NR	57.0–60.0	2.92–3.70	–1.13–0.58	NR	Pla, 2008
Bianca italiana rabbit	NR	24.62–26.18	0.93–1.09	NR	NR	NR	NR	5.72–5.75	Liu et al., 2009
Synthetic Line R rabbits	NR	NR	NR	NR	50.17–50.63	5.29–5.86	2.47–2.85	6.00–6.02	Ramírez et al., 2004

CP, crude protein; CF, crude fiber; NR, not reported.

purchasing decision of meat and meat products by consumers is mainly associated with the attractive appearance of the final product (Sujiwo et al., 2019). Overall, the CIE L* of different rabbit breeds ranges from 41.78–65.68. Czech White and Moravian White rabbit breeds had the highest CIE L* of *bicep femoris* (BF) muscles than Czech gold breeds, still, the Hyplus rabbits had average CIE L* compared to other local breeds (Chodová et al., 2014). Wang et al. (2016) revealed meat colour differences from *longissimus lumborum* (LL) and BF muscles of three rabbit genotypes, the highest CIE L*, CIE a*, and CIE b* were reported in Hyla (59.96–63.16), Tianfu Black (5.10–5.46) and Champagne (6.66–6.75) breeds for both muscles, respectively (Table 1). The higher proportion of myoglobin content and the type of muscle fibers might be contributed to more CIE a*, despite it could be affected by other factors such as exercise, diet, and genetic and environmental factors (Joo et al., 2013). In addition, the pH has a significant role in the keeping qualities of meat because it affects the protein structures and degradation, water holding capacity, colour, juiciness, and shelf life (Hulot and Ouhayoun, 1999). The pH range of commercial hybrids rabbit meat was 5.62–5.88 (Liste et al., 2009; Mancini et al., 2018; Mazzone et al., 2010; Paci et al., 2012; Table 1), whereas Vienna Blue and Burgundy Fawn breeds also had a similar pH range of commercial hybrid rabbit (Dalle Zotte et al., 2016). In contrast, the ultimate pH (pHu) of the SIKA breed was lower than hybrids, whilst sex and slaughter age were significantly contributed to this reduction in ultimate pH (Gašperlin et al., 2006). The pH of crossbreds of New Zealand White and California was 6.02–6.08 (Secci et al., 2020) which is almost similar to synthetic line R rabbits (Ramírez et al., 2004). Chinese rabbit breeds, such as Hyla (6.56), Champagne (6.48), and Tianfu Black (6.67) had higher pH compared to other rabbit breeds (Table 1; Wang et al., 2016).

The proximate composition and pH values of rabbit meat obtained from different anatomical location of muscles was represented in Table 2. In accordance, North et al. (2018) recorded the crude fat content of hind leg muscles of New Zealand White rabbit breeds was in the range of 6.32%–6.56%. However, the crude fat content of *longissimus thorasis et lumborum* (LTL) muscles of the same rabbit breeds was about two folds lower than hind legs (2.88%–2.92%). Both LTL and hind leg muscles of rabbit meat had approximately 1.20%–1.25% of ash content (Table 2; Dabbou et al., 2017; D'Agata et al., 2009; North et al., 2018; Pla, 2008).

The LL muscles had lower pH of 5.38–5.83 (D'Agata et al., 2009; Dal Bosco et al., 2012; Dalle Zotte et al., 2016; Koné et al., 2019; Liu et al., 2012; Paci et al., 2012; Paci et al., 2013; Perna et al., 2019; Table 2) compared to BF muscles (5.64–6.23) in rabbit (D'Agata et al., 2009; Dalle Zotte et al., 2016; Koné et al., 2016; Koné et al., 2019; Mancini et al., 2018; Paci et al., 2013). These slight differences in pH among different muscles might be from their glycolytic potential (Parigi Bini et al., 1992).

Table 2. Proximate composition and pH values of rabbit meat obtained from different anatomical location of muscles

Muscle	Moisture	CP%	CF%	Ash%	pH	References
LD	66.50–75.50	17.90–24.10	0.44–3.18	0.67–1.57	5.57–6.67	Koné et al., 2016; Mattioli et al., 2017; Simonová et al., 2020; Wang et al., 2016
LL	72.29–75.24	20.62–25.08	0.95–3.04	1.12–1.55	5.38–5.83	D'Agata et al., 2009; Dal Bosco et al., 2012; Dalle Zotte et al., 2016; Koné et al., 2019; Liu et al., 2012; Paci et al., 2012; Paci et al., 2013; Perna et al., 2019
LTL	73.30–75.11	22.50–26.18	0.87–2.92	1.20–1.25	5.58–6.08	Dabbou et al., 2017; Mancini et al., 2018; Menchetti et al., 2020; North et al., 2018; Secci et al., 2020
BF	72.10–75.60	20.00–22.94	1.12–6.56	1.20–1.25	5.64–6.23	D'Agata et al., 2009; Dalle Zotte et al., 2016; Koné et al., 2016; Koné et al., 2019; Mancini et al., 2018; North et al., 2018; Paci et al., 2013; Pla, 2008

CP, crude protein; CF, crude fiber; LD, *Longissimus dorsi*; LL, *Longissimus lumborum*; LTL, *Longissimus thorasis et lumborum*; BF, *Bicep femoris*.

Fatty acids

In terms of total fatty acids, the rabbit breeds such as New Zealand White, Grimaud, *Bianca italiana* rabbit, Pannon White, and Grey coloured local rabbits had the highest proportion of saturated fatty acid (SFA) and followed by polyunsaturated fatty acid (PUFA) and monounsaturated fatty acid (MUFA; Dabbou et al., 2017; D'Agata et al., 2009; Dalle Zotte et al., 2009; Liu et al., 2009; Mattioli et al., 2017; Table 3). In contrast, synthetic rabbit lines were shown the highest proportion of PUFA, followed by SFA and MUFA (Martínez-Álvaro et al., 2018; Papadomichelakis et al., 2017 respectively; Table 3). On the other hand, wild rabbits could be recommended as a good source of *n*-3 fatty acids (6.89%–13.27% of total fatty acids; Papadomichelakis et al., 2017), whilst synthetic rabbit lines have abundant *n*-6 with about 39.5% of total fatty acids (Martínez-Álvaro et al., 2018). In fact, the composition of fatty acids in different rabbit meat might be varied due to the level and source of fat in the diet added to alter the *n*-6 to *n*-3 ratio (Tres et al., 2008).

The high percentage of SFA, followed by PUFA and MUFA pattern were observed in the LL muscle (Dal Bosco et al., 2012; Papadomichelakis et al., 2017; Perna et al., 2019), LTL muscles (Dabbou et al., 2017; Liu et al., 2009) and loin muscles (Mattioli et al., 2017; Secci et al., 2019) which are represented in Table 3. The LL muscle was identified as a good nutritive value because it had higher ratios of *n*-3/*n*-6, PUFA/SFA, and atherogenicity index (AI; Dal Bosco et al., 2012; Papadomichelakis et al., 2017; Perna et al., 2019) compared to other muscles.

Sensory characteristics

Flavour is one of the sensory attributes that include olfactory (smell and aroma) and gustative (taste) perceptions (Ouhayoun and Dalle Zotte, 1996). Rabbit meat has a typical smell of grass (Li et al., 2018). It has been reported that more than 75 volatile flavor compounds have been found in rabbit meat, including acids, alcohols, ketones, esters, aldehydes, ethers, heterocyclic, and hydrocarbons. Based on the odour-active values, hexanal, nonanal, hexanoic acid, octanal, 1-octen-3-ol, and (*E, E*)-2,4-decadienal were considered as the key flavor components in rabbit meat (Wang et al., 2013; Xie et al., 2016). Furthermore, furan derivatives, amines, and intermediate aldehydes, especially hexanoic acid, hexanal, pentanal, and 2-pentyl furan, were recommended as the major components for the unique odor of rabbit meat (Xie et al., 2016).

The consumption of rabbit meat by consumers is also affected by this typical grass smell. The problem could be overcomed by the application of deodorizing methods, such as, soaking the rabbit meat in acid, alkali, and brewer's yeast, which aids to reduce aldehydes in the meat (Li et al., 2018). However, it is a general suggested deodorizing method for rabbit meat because the presence of specific volatile compounds of each rabbit breeds were not yet studied.

Factors Affecting Carcass and Meat Quality Traits of Rabbit

Genetic factor

Genetic improvement of parental lines of rabbits is commonly considered during their selection for growth traits and this might affect carcass composition and meat quality (Pascual and Pla, 2007). In this regard, hybrids or genetic lines for fast growth have been taken into more consideration than local genotypes (Princz et al., 2009). In addition, the potential genetic improvement of rabbit meat characteristics is decided by the occurrence of specific genes in rabbits. Accordingly, Wang et al. (2017) proposed myogenic factor 5 (Myf5) single nucleotide polymorphism could be considered as a potential genetic marker for good meat quality selection in breeding programmes of Ira and Tianfu Black breed since it plays significant roles in muscle fiber formation and transcription of muscle-specific genes (Ujan et al., 2011). Apart from Myf5, calpastatin and

Table 3. Fatty acids and lipid indices (expressed as %) of different rabbit breeds and anatomical location of muscles

Variable	SFA	MUFA	PUFA	*n*-3	*n*-6	*n*3/*n*6	*n*6/*n*3	PUFA/SFA	AI	TI	h/H	References
Breeds												
New Zealand White× California	0.84–36.82	0.63–23.67	NR	0.06–4.68	0.80–37.64	NR	11.32–14.43	NR	NR	NR	NR	Secci et al., 2020
New Zealand White	34.70–50.11	21.00–36.52	20.58–40.70	2.47–4.28	17.21–25.99	0.17–4.40	4.89–9.06	0.90–1.10	0.60–1.25	0.84–2.23	1.54–1.78	Dal Bosco et al., 2012; Mattioli et al., 2017; Perna et al., 2019; Rasinska et al., 2018
Russian rabbit	19.00–24.30	18.80–46.60	34.40–56.90	NR	NR	0.30–0.40	NR	NR	NR	NR	NR	Alekseeva et al., 2018
Synthetic rabbit line	38.20	24.80	41.80	2.92	39.50	NR	NR	NR	NR	NR	NR	Martínez-Álvaro et al., 2018
Wild rabbits (*Oryctolagus cuniculus*)	27.67–29.54	12.02–14.47	38.78–41.11	6.89–13.27	25.16–32.00	NR	2.02–4.70	1.32–1.49	0.37–0.43	0.49–0.69	NR	Papadomichelakis et al., 2017
Crossbred (Grimaud)	36.48–42.93	25.90–30.99	26.08–37.46	2.47–9.64	22.94–27.40	NR	2.88–9.30	0.61–1.03	0.52–0.72	0.59–1.14	NR	Dabbou et al., 2017
Bianca italiana rabbit	42.22–42.98	26.22–27.03	31.55–32.42	2.04–2.09	29.46–30.38	31.53–32.42	NR	0.75	NR	NR	RNR	Liu et al., 2009
Pannon White	37.40–38.50	26.10–26.50	35.30–36.00	NR	NR	NR	7.96–8.51	NR	NR	NR	NR	Dalle zotte et al., 2009
Grey coloured local rabbits (agouti or wild-type)	36.42–37.85	21.94–23.22	34.18–34.74	2.40–2.46	32.16–32.94	NR	0.52–0.57	0.92–0.94	NR	NR	NR	D'Agata et al., 2009
Spanish rabbits	41.30–42.60	29.40–35.60	21.90–28.90	2.40–2.70	19.40–25.30	NR	8.10–9.30	NR	NR	NR	NR	Pla, 2008
Anatomical location of muscles												
LD	38.20	24.80	41.80	2.92	39.50	NR	NR	NR	NR	NR	NR	Martínez-Álvaro et al., 2018
LL	27.67–50.11	12.02–36.52	20.58–41.11	3.10–13.27	17.21–32.00	0.17–0.21	2.02–5.55	1.32–1.49	0.37–0.91	0.49–1.47	NR	Dal Bosco et al., 2012; Papadomichelakis et al., 2017; Perna et al., 2019
LTL	36.48–42.98	25.90–30.99	26.08–37.46	2.04–9.64	22.94–30.38	NR	2.88–9.30	0.61–1.03	0.52–0.72	0.59–1.14	NR	Dabbou et al., 2017; Liu et al., 2009
Loin muscle	34.70–39.90	21.86–25.40	35.30–39.30	4.11–4.68	35.23–37.64	2.80–3.40	NR	0.90–1.10	NR	NR	NR	Mattioli et al., 2017; Secci et al., 2019
Hind leg	36.30–40.40	21.00–24.30	34.18–40.70	2.40–2.46	32.16–32.94	3.60–4.40	0.52–0.57	0.91–1.10	NR	NR	NR	Mattioli et al., 2017

SFA, saturated fatty acids; MUFA, mono unsaturated fatty acids; PUFA, poly unsaturated fatty acids; AI, atherogenicity index; TI, thrombogenicity index; h/H, hypocholesterolemic/hypercholesterolemic ratio; NR, not reported; LD, *Longissimus dorsi*; LL, *Longissimus lumborum*; LTL, *Longissimus thorasis et lumborum*.

myopalladin (*MYPN*) could also be considered as candidate genes for the genetic improvement of rabbit meat traits (Li et al., 2018; Wang et al., 2017). Further, Wang et al. (2017) summarized specific gene sequences in Ira rabbits responsible for different meat qualities. Accordingly, genotypes of GG-AA-AA and AA-AG-AG could be used as genetic markers for increasing intramuscular fat and enhancing meat CIE a* and CIE b* in BF muscles, respectively. Similarly, rabbits with

AAACTG haplotypes were used as a genetic marker to determine the good meat quality traits in rabbits. However, molecular genetics and gene sequencing-based studies on different rabbit breeds are more important to detect responsible gene sequences for different meat quality traits.

The genetic variability in physiological characteristics among pure breeds of rabbits is very high; for instance, a Flemish giant rabbit (*Oryctolagus cuniculus domesticus*) is five times heavier than a Netherlands Dwarf type at the adult weight (Dalle Zotte, 2002). The German giant (Risen)–one of the famous meat-skin type rabbit breeds–had recorded a soft and juicy texture in meat (Alekseeva et al., 2018). Slaughter weights of giant breeds Moravian Blue and the medium breeds Czech White were higher than commercial hybrid Hyplus (Chodová et al., 2014).

It has been identified that local populations had lower carcass yield and poor carcass quality attributes, such as meatiness, fatness, colur of muscles and fat, and meat:bone ratio than hybrid lines at the commercial market weight (about 2.5 kg). In contrast, local genotypes produce heavier carcasses than hybrid lines when they were slaughtered at an older age (D'Agata et al., 2009; Pla, 2008) because an increase in age encouraged them to gain more muscles. Chodová et al. (2014) reported that the weight of hind and loin parts was influenced by the size of breeds and genotype, respectively. Accordingly, the giant breed Moravian Blue had excellent weights for both hind and loin parts compared to commercial hybrid lines. Polak et al. (2006) outlined rabbits originated from the mother line and a hybrid of the father and mother line of SIKA genotypes contributed significant differences in colour parameters except CIE b* and for more tenderness in meat than those of father lines. However, the correlation between genetic lines and carcass quality attributes is very limited. Therefore, in-depth studies on the effect of genotypes of rabbits on carcass and meat quality attributes are necessary to provide a solid interpretation (Paci et al., 2012).

Age

Rabbit meat quality is prominently influenced by the live weight of a rabbit and age at slaughter (Dalle Zotte, 2002; Szendrő et al., 2010). The approximate slaughter weight of a rabbit is 2 kg; however, it varies depending on the needs of the commercial market in different countries (Pascual and Pla, 2007). Several studies conducted that the live weights of rabbits slaughtered at about 70, 80, 90, and 100 days were 1.86–2.24 kg (Perna et al., 2019; Wang et al., 2016), 2.46–2.53 kg (Liu et al., 2009; Mazzone et al., 2010), 2.0–2.49 kg (Mancini et al., 2018; Menchetti et al., 2020; Pla, 2008) and 2.14–3.27 kg (D'Agata et al., 2009; Perna et al., 2019), respectively. However, it was evident that rabbit has a larger proportion of intestinal content, a decrease in carcass recovery percentage, and the reduction of fat deposits (Khalil and Al-Saef, 2008). However, it is difficult to conclude regarding the effect of age on carcass weight because the above-mentioned findings were conducted in different rabbit breeds, reared under different management practices, and changes in environmental conditions.

Bivolarski et al. (2011) demonstrated the effect of weaning age on meat and carcass characters in rabbits. The findings revealed that early-weaned rabbits possessed (21 days) significantly lower live weight, carcass weight, dressing percentage, and pH than normally weaned rabbits (35 days) due to differences in growth performances with respect to their age. As age increases, glycolytic energy metabolism increases, and oxidative metabolism, myoglobin level, and ultimate pH decrease (Dalle Zotte et al., 1996).

Tenderness was positively correlated with intramuscular fat and within age groups. Rabbits at 18 weeks old had tenderer and less fibrous LL muscle than those of 11 weeks old (Gondret et al., 1998). It is generally decreased with an increase in age, in relation to a decline in the solubility of collagen. Hence, Gondret et al. (1998) interpreted that increase in tenderness with age could be partly attributed to the noticeable age-related intramuscular fat content in the LL muscle of rabbits or changes in energy metabolism.

Environmental factors

Animal welfare and environmental enrichment such as temperature, relative humidity, and ventilation had been importantly considered during animal production (D'Agata et al., 2009; Dalle Zotte, 2002; Dalle Zotte et al., 2009; Liu et al., 2012). High ambient temperature is a major stress factor for rabbits because of their non-functional sweat glands (Zeferino et al., 2013). In accordance, ambient temperatures above the evaporative critical temperature (16.5℃ in summer and 21.4℃ in winter) cause adverse effects on live weight gain, meat quality, and health in rabbits (Marai et al., 2002). A similar pattern of negative results was observed in hybrid rabbits reared under intensive conditions (Zeferino et al., 2013). Moreover, high ambient temperature initiates lipid oxidation in cell membranes and it may also accelerate post-mortem metabolism and biochemical changes in muscle, such as lower pH, higher CIE L*, and drip loss (Sahin and Kucuk, 2003). To alleviate the negative effects of high ambient temperature, diets enriched with natural antioxidants such as polysaccharides and tannins could be used, which protect cells and tissues from lipoperoxidation damage (Liu et al., 2011).

Rabbits are usually kept either in cages or pens under an intensive rearing system. The European rabbit production has outlined the characteristics of the standard fattening system, emphasizing a 10% of mortality rate, 2.70 kg of live weight at slaughter, 2.85 feed conversion ratio, and 79 days old of age at slaughter. The climate change values are increased by the longer rearing of rabbits than the standard period, whereas, emissions from manure are also contributed to acidification, terrestrial eutrophication, and elevate CO_2 and CH_4 levels in the rabbit farm. These all direct and indirect inputs and emissions influence on rabbit production efficiency. The cage housing system is mainly used to keep bucks and does individually made by either wire-meshed nets or wood or bamboo, whereas, the pen housing system is widely applied for fattening or weaned rabbits kept as a group. The growth performance and meat yield are generally higher in farm animals reared under intensive than extensive rearing system.

In contrast, rabbits kept in outdoor housing system had higher slaughter weights than those of indoor rabbits (2,535 g vs 2,137 g; p<0.01), while carcass yield was higher in rabbits kept in indoor housing system (57.8% vs 58.4%; p<0.05) due to the higher skin percentage in outdoor rabbits (D'Agata et al., 2009). However, housing systems do not significantly influence on meat to bone ratio, and textural measurements, in particular, shear force in rabbits (D'Agata et al., 2009; Secci et al., 2019). Further, Dalle Zotte et al. (2009) demonstrated the effect of interactions of housing systems (cage vs pen) and gnawing stick, as well as, floor type (wire mesh vs. plastic net) and gnawing stick on rabbit meat quality. Accordingly, slaughter weight and the weight of hot and chilled carcasses were significantly affected by both types of interactions, in contrast, slaughter yield percentage, reference carcasses percentage, and meat to bone ratio were not significantly affected by them.

Meanwhile, several studies were conducted on obtaining rabbit meat from less intensive rearing system. For that, they evaluate the effect of stocking density, floor type, and group size on rabbit meat quality in order to find out the suitable alternative rearing methods for rabbits maintained in intensive management production (Dalle Zotte et al., 2016; Szendrő and Dalle Zotte, 2011). Stocking density is one of the important factor in terms of production aspects and well being of rabbits. Paci et al. (2013) reported that dressing percentage, slaughter weight, pHu and meat to bone ratio were not generally affected by the different stocking densities of rabbits. But, rabbits kept at 2.5 rabbits/m^2 had slightly higher dressing out percentages compared with 5 and 16 rabbits/m^2 because of the higher frequency of aggressiveness and stressful conditions (Matics et al., 2014). Apart from that, the pHu values of LL and BF muscles of the 16 rabbits/cage group showed significantly higher than the 8 and 4 rabbits/cage groups (Paci et al., 2013). Trocino et al. (2004) studied the effect of two stocking densities (12.1

rabbits/m^2 and 16.0 rabbits/m^2) and compared two-floor types (galvanized wire net and galvanized steel bars) within cages on meat quality traits of rabbits slaughtered at 71 days of age. However, these conditions did not significantly influence muscle to bone ratio (7.98 vs. 7.89; 7.96 vs. 7.91 respectively) and cold dressing out percentage (58.7 vs. 58.9; 58.8 vs. 58.7, respectively). On the other hand, dressing out percentage, skin percentage, and meat to bone ratio were significantly affected by group size on rabbit carcass traits (Paci et al., 2013).

Diet

Once rabbits are selected for fast growth, proper feeding management should also be considered to provide the optimum level of digestible energy (DE), crude protein, crude fiber, and other feed additives which significantly enhance the carcass attributes. Previous research has compared the effect of *ad libitum* and restricted feeding on growth performance, and carcass and meat quality characteristics (Metzger et al., 2008). In addition, the inclusion of feed alternatives in animal feed is one of the effective modes to enhance rapid growth and sustainability. Plenty of alternatives such as probiotics, prebiotics, organic acids, herbs and herbal extracts, enzymes, proteins, fatty acids, vitamins, and selenium were tested in rabbits to stabilize and improve health, and to increase the ultimate production and economic viability of rabbit farms (Dalle Zotte et al., 2016; Simonová et al., 2020).

Dalle Zotte et al. (1996) demonstrated that diet with a high energy content (12.16 MJ/kg) fed to rabbits from post-weaning to slaughter enhanced dissectible fat content and decreased the pHu in LL muscle. Similar results were observed by Carraro et al. (2007) when the starch level of feed was increased from 120 to 180 g/kg. In addition, Xiccato et al. (2002) reported that increasing starch content in feed enhanced slaughter yield in rabbits. However, increasing the dietary starch to acid detergent fiber (ADF) ratio during the fattening period did not affect the slaughter yield, carcass adiposity, and meatiness (Sartori et al., 2003).

Increasing crude fibre content (138, 163, and 198 g/kg) and decreasing energy level (10.2, 9.3, and 8.6 MJ/kg) in feed did not significantly affect the slaughter yield, carcass meatiness, or fatness in a rabbit. However, rabbits fed a more fibrous diet resulted in significantly leaner hind legs (Parigi Bini et al., 1992). These findings were further confirmed by the study of Carrilho et al. (2009); neither dietary crude fibre content nor the digestible fibre to ADF ratio affected carcass or meat quality.

A greater muscle growth would be gained, if the feed contains 10.5–11.0 g/MJ of digestible protein (DP) to DE ratio because it allows for the maximum expression of muscle protein synthesis. Increasing the ratio of DP to DE above 12 g/MJ caused significant reductions in dissectible fat deposit, whereas, above 14 g/MJ reduced meatiness in rabbit meat (Dalle Zotte, 2002). Furthermore, Carabaño et al. (2008) recommended adopting protein levels of 140 g/kg in commercial feeds from weaning to slaughter to improve the quality traits of rabbit meat.

Feed restriction could be either quantitative in terms of the proportion of restriction of the *ad libitum* intake and length or qualitative by lowering DE to less than 9.2 MJ/kg to improve the feed conversion ratio (Hernández and Zotte, 2010). The maximum outcome was achieved by early feed restriction followed by *ad libitum* feed intake (DE greater than 10.45 MJ/kg) because late restriction, after 56 days of age, reduced rabbit loin and perirenal fat incidence. Regarding meat and carcass quality traits, quantitative feed restriction in rabbits (less than 85% of the *ad libitum* diet) highly influenced on slaughter yield, carcass adiposity, and lipid content, whereas increased cooking loss, higher CIE L*, and lower CIE a* in *longissimus dorsi* (LD) muscle were observed in rabbit meat reared at 85%–90% of feed restriction from 4 weeks to slaughter at 11 weeks of age (Metzger et al., 2008). Larzul et al. (2004) practiced restricted feeding for Rex du Poitou® breed from 8 to 18 weeks of age to limit the carcass adiposity and to achieve the French standard slaughter weight (2.4 kg). Further, feed restriction in rabbits lowered the meat to bone ratio and intramuscular fat content in LD muscle (Hernández and Zotte, 2010). Comparatively, rabbits fed *ad libitum* were heavier and fattier and had a higher dressing percentage and proportion of muscle than those exposed to restricted feeding (Larzul et al., 2004).

Probiotics are integrated with rabbit rations to improve gut immunity, digestion, gastrointestinal microflora, and enzymatic activity (Lauková et al., 2016; Simonová et al., 2020). In addition, feed supplemented with probiotics contributed to an increase in body weight (Lauková et al., 2016; Matusevičius et al., 2006; Simonová et al., 2020). However, dietary supplementation with prebiotics did not enhance the conjugated linoleic acid (CLA) and linolenic acid (C18:3 n-3) in rabbit meat (Mattioli et al., 2017).

Supplementation of the diet with vitamin C and vitamin E has been found to reduce lipid oxidation in rabbit meat during different storage conditions (Castellini et al., 2001). Besides studies related to the inclusion of vitamin E in rabbit diet have increased body weight, dressing percentage, and hot carcass weight and reduced drip loss in meat (Eiben et al., 2011). In general, herbs and extracts of spices comprise phytochemical compounds such as phenolic compounds and tannins which act as natural antioxidants (Dalle Zotte et al., 2016; López de Dicastillo et al., 2017). Interestingly, the use of antioxidants (vitamin E) in rabbit diets manipulated the composition of tissue lipids with a high PUFA content and also enhanced the oxidative stability of meat (Hernández, 2008). Supplementation of α-tocopherol in the diet had a strong relationship with meat and carcass quality traits of rabbits (Dal Bosco et al., 2001). Accordingly, rabbits fed α-tocopheryl acetate (240 mg/kg) had significantly greater body weight at slaughter and carcass weight, and also improve oxidative stability and overall quality of meat (Ebeid et al., 2013). On the other hand, α-tocopherol at 100 mg/kg of feed increased its content in rabbit meat by three folds (Tres et al., 2008).

Inclusion of dietary fat in low or moderate concentrations (20–60 g/kg and 3%–6%, respectively) increased the carcass yield and total dissectible fat level in rabbit meat (Meineri et al., 2010). Moreover, it influenced the physical properties of rabbit meat with increases in pHu and cooking loss (Meineri et al., 2010). Tres et al. (2008) evaluated the effects of replacing beef tallow added to rabbit feeds with different levels (0%, 1.5%, and 3%) of sunflower and linseed oil. Replacement of beef tallow by vegetable fats enhanced PUFA, however, the 3% inclusion of linseed oil in feed increased meat oxidation and reduced its oxidative stability. Perilla (*Perilla frutescens*) seeds supplemented diet increased CIE a* in BF than LD muscle in rabbits (Peiretti et al., 2011). Petacchi et al. (2005) marked that the inclusion of dietary CLA in the diet increased the amount of CLA in the intramuscular lipids of rabbits and lean tissue deposition (Corino et al., 2003). However, the efficiency depends on the age of the rabbit and the dosage level of CLA supplementation (Corino et al., 2002). For instance, high inclusion level of CLA in the diet at about 5 g/kg significantly decreased lipid content in rabbit meat (Corino et al., 2003).

Alagón et al. (2015) studied the effect of dietary inclusion of distillers dried grains with solubles (DDGS) on carcass and meat quality of rabbits and found no significant differences in intramuscular fat, water holding capacity, cooking loss, and textural parameters at an inclusion level. However, barley and corn DDGS increased dissectible fat percentage whereas wheat DDGS enhanced the CIE a* of meat. Rabbits fed a higher dosage (2 kg/t) of natural extract from *Lippia citriodora* showed higher tenderness and juiciness in meat compared to a low dosage of 1 kg/t (Palazzo et al., 2015). In addition, rabbits fed byproducts of tomato processing (3%) had significantly higher slaughter weight and dressing out percentage and lower proportions of liver and kidney than rabbits fed with 6% (Peiretti et al., 2013). Rabbits fed 0.2% oregano (*Origanum vulgare*) and 0.1% oregano+0.1% rosemary (*Rosmarinus officinalis*) had significantly ($p<0.01$) higher carcass weight, live weight, and average daily gain compared with those fed 0.2% rosemary (Cardinali et al., 2015).

Moderate inclusion of indigenous feedstuff (alfalfa hay, barley, and wheat bran; 65%) in rabbit diet significantly improved slaughter weight and dressing percentage compared to low (42.5%) and higher (87.5%) inclusions. Peiretti and Meineri (2011) observed greater slaughter weights and dressing percentages in rabbits fed blue-green algae (*Spirulina platensis*) at 100 g/kg. In contrast, rabbits fed with blue-green algae at 150 g/kg than 50 g/kg and 100 g/kg of inclusion led to a lower proportion of leg and breast parts. Increasing levels of *Spirulina* declined omega-3 PUFA, but elevated lipid oxidation lowered the carcass and meat quality.

Pre-slaughter conditions

Pre-slaughter and post-slaughter handling have identified that it has less impact on the meat quality of rabbits as it is lean meat compared to other species (Ouhayoun, 1992). Despite this, literature still revealed that pre-slaughter conditions influenced on the ante and post-mortem biochemical processes and, therefore, meat quality of rabbits (Sabuncuoglu et al., 2011).

Starvation affects the pHu of muscle, reduces carcass yield, and, of course, animal welfare (María et al., 2006). Cavani and Petracci (2004) revealed increasing time duration of fasting causes body weight losses in rabbits. Accordingly, weight loss occurred about 3%–6% and 8%–12% of their body weight when rabbits were allowed for 12 hours and 36–48 hours of fasting, respectively.

Lambertini et al. (2006) reported that the longer transport time significantly lowered the slaughter weight compared to animals transported for the shortest time (4 hours: 2,422 g vs. 1 hour: 2,488 g; $p<0.01$). But dressing percentage was similar in both treatments with no significant differences (61.3%). The pH value of meat at 24 hours exhibited significant differences concerning transport time (4 hours: 6.01 vs. 2 hours: 5.88; $p<0.05$) because shorter transportation promotes the meat acidification process by accumulating lactate in muscles. Trocino et al. (2003) emphasized weight loss occurred in rabbits due to dehydration when they were exposed to 6–8 hours of transport, thus, lowering meat quality.

Lairage is a place where rabbits are unloaded from the truck and wait for slaughtering in designated holding pens (Składanowska-Baryza and Stanisz, 2019). The corticosterone level elevates in the blood of rabbits when they are prone to stress, including transportation stress (Składanowska-Baryza et al., 2018). The elevated cortisol level in the blood is associated with lower meatiness and causes stress before slaughter. It tends to reduce pH, lower water binding capacity, lighter colour and possibly tough meat. The lairage time minimizes the consequences of transport stress and decreases corticosterone levels (Verga et al., 2009). Liste et al. (2009) reported similar results. Accordingly, the corticosterone level was significantly higher in rabbits after 2 hours of lairage compared to 8 hours. Both treatments recorded almost the same pH values (5.8), but 2 hours of lairage had higher scores for tenderness than 8 hours of lairage (Liste et al., 2009).

Stunning is practiced to minimize the suffering and pain of animals. There are various stunning methods, including electrical, mechanical, and gas stunning (Apata et al., 2012). According to Składanowska-Baryza et al. (2020), body weight at slaughter was high in rabbits stunned by hitting the head with a narrow rod compared to those of non-penetrating captive bolt and electrical stunning (49 V for 15 seconds) methods. High dressing out percentage and lower pH at 24 hours after slaughtering were observed in electrically stunned rabbits than in mechanically stunned rabbits (Składanowska-Baryza et al., 2020). The pH of muscles 24 hours post-mortem from mechanically stunned rabbits was lower compared to the electrically stunned animals (Lafuente and López, 2014). Tenderness and juiciness were improved in high voltage and frequency (130 V and 172 Hz) than in medium voltage and frequency levels (49 V and 250 Hz). Mechanical stunned rabbits had high body weight compared to electrically stunned rabbits. López et al. (2008) compared electrical stunning to the halal slaughter and found that the performance of the halal slaughter does not negatively affect instrumental meat quality characteristics. They further found that the pH at 24 hours post-mortem was lower in meat from animals submitted to halal slaughter compared to those electrically stunned (49 V and 250 Hz for less than 2 seconds). It could be the result of lower lactic acid content in the muscles post-mortem. Apata et al. (2012) outlined all palatability traits were better in meat from rabbits stunned with gas compared to halal slaughter, in which, cooking loss, thermal shortening, and drip loss of meat were lower when the rabbits were stunned with gas.

During loading and unloading, body parts may injure and it causes bruises in carcasses, especially the thoracic region, legs, and inner loin (Buil et al., 2004). Similar meat defects might happen during the transportation, e.g. cage position and lying during transport. Nonetheless, the position of the truck (top, middle, and bottom) in the multi-floor cage rolling stand did not influence meat quality measurements (María et al., 2006). Mazzone et al. (2010) stated loading methods did not significantly affect meat quality traits, mainly pHu and pH loss.

Post-slaughter processing factors

Post-slaughter phase is one of the crucial points in rabbit production which can influence meat and carcass quality (Cavani et al., 2009). Thus, proper storage temperature and packaging method should be adopted to maintain the integrity of the carcass quality. Storage temperature can affect the changes in meat quality (Lan et al., 2016). Low-temperature storage above or below its freezing point is one of the preservation techniques used to keep the freshness of meat (Zhou et al., 2010). Conventional chilling, super-chilling, and frozen methods are applied to preserve rabbit meat (Cullere et al., 2018; Jia et al., 2017). Wang et al. (2018) interpreted the changes in metmyoglobin (MetMb) proportion in rabbit meat stored in refrigerated and super-chilling storage conditions. Accordingly, the percentage of MetMb was comparatively higher in refrigerated conditions than in super-chilling over the storage period. It might be in super-chilling and the redox stability of myoglobin (Wang et al., 2018).

Both fresh and processed rabbit meat products are generally chilled and frozen (Li et al., 2018). In terms of shelf life, frozen rabbit meat has an extended shelf life. However, the physicochemical properties and sensory quality of frozen rabbits are naturally altered during storage and thawing (Lan et al., 2016). Regarding pH, rabbit meat stored at –12℃ and –18℃ did not exhibit significant differences over the storage period. But samples stored at 4℃ were gradually increased, meanwhile, samples at –4℃ showed a decline for 10 days and increased during the rest of the storage period (Wang et al., 2020). However, samples stored at 4℃, –4℃, –12℃, and –18℃ revealed similar patterns with regards to colour parameters, as increasing trends for CIE L* and CIE a* and decreasing trends for CIE b*. Secci et al. (2020) reported that the use of mirrors in the free-range areas had a significant difference in weight loss, pH, and colour of rabbit meat stored at –10℃ for 80 days. In contrast, the interaction between storage and farming systems did not indicate any significant difference in weight loss, pH, and CIE L*, except CIE a* ($p<0.05$). Wang et al. (2018) verified the amount of MetMb in rabbit meat considerably increased ($p<0.05$) until 10 days of super-chilled storage (–3.5±0.5℃) and remained constant thereafter ($p>0.05$). Moreover, Lan et al. (2016) reported that the chilling method lowered the drip loss of rabbit hind legs compared with the super-chilled method. In addition, a higher drip loss was displayed in rabbit meat stored at –2.5℃ compared with the samples stored at –4℃. This might be occurred due to the consequences of a higher rate of proteolysis at higher temperatures caused by the activity of bacterial enzymes and endogenous enzymes (Olsson et al., 2007).

Apart from low-temperature storage, proper packaging could be an alternative strategy to preserve rabbit meat from oxidation as species-specific characteristics, management, and environmental conditions make rabbit meat susceptible to oxidative phenomena (Lorenzo et al., 2014). Pereira and Malfeito-Ferreira (2015) compared the different packing methods on rabbit meat quality. Accordingly, rabbit carcasses packed in bulk, packed under air, and in a modified atmosphere (30% O_2: 40% CO_2: 30% N_2) exhibited a pH varied between 6.01–6.36. Similarly, Rodríguez-Calleja et al. (2010) mentioned the time of chilled storage at 3±1℃ of rabbit meat packaged under vacuum, 100% CO_2, and a commercial gas blend (35% CO_2: 35% O_2: 30% N_2) did not significantly affect the pH. They recommended the commercial atmosphere as the most effective method to maintain the rabbit meat color. Dal Bosco et al. (2018) outlined that the time of storage and the packaging affected the oxidative status of rabbit meat under the retail display and the packaging method itself significantly reduced the antioxidant content of loin meat.

Biological Activities of Rabbit Meat

Fatty acids in cardiovascular health

In terms of the nutritive value of foods, the Department of Health and Social Security (1994) London, recommended a ratio of 0.45 or higher for PUFA/SFA in foods to prevent cardiovascular diseases. Accordingly, wild rabbits had the highest PUFA/SFA ratio of 1.32–1.49 (Papadomichelakis et al., 2017) compared to other commercial rabbit breeds. New Zealand White rabbits (0.9–1.1; Mattioli et al., 2017), Grimaud breeds (0.61–1.03; Dabbou et al., 2017), and Grey-coloured rabbit breeds (0.92–0.94; D'Agata et al., 2009) had also better PUFA/SFA ratio than the recommended level. Also, the $n3/n6$ fatty acids ratio is recommended greater than 1.0 for a well-balanced diet (Bhardwaj et al., 2016). Mattioli et al. (2017) reported New Zealand White breed satisfied the recommended ratio of $n3/n6$ fatty acids (2.8–4.4). The cholesterol effect of a fat source is expressed by a ratio of hypocholesterolemic/hypercholesterolemic (h/H; Sinanoglou et al., 2015). New Zealand White breeds had approximately 1.54–1.78 (Rasinska et al., 2018) compared to other rabbit breeds. The AI and thrombogenicity index (TI) should be lower than 1.0 in foods for atherosclerosis and thrombosis prevention, respectively (Bobe et al., 2004). In this regard, wild rabbits satisfied both AI (0.3–0.43) and TI (0.49–0.69) indices within the recommended level (Papadomichelakis et al., 2017). Grimaud breed had better AI (0.52–0.72), however, TI (0.59–1.14) somewhat exceeded the recommended level (Dabbou et al., 2017).

Antihypertensive properties

Rabbit meat is also considered as a healthy meat food and suggested for patients with hypertension, hyperlipidemia, cardiovascular, and cerebrovascular diseases (Chen et al., 2021). Synthetic ACE inhibitors are broadly used to control hypertension, however, long-term intake of such synthetic drugs can lead to cause side effects such as decreased kidney function and increased risk of lung cancer (Hicks et al., 2018). Hence, ACE-inhibitory peptides derived from natural sources could provide safer therapies (Chen et al., 2022).

Proteins in rabbit meat are primarily found in the muscle (Chen et al., 2021). Chen et al. (2022) reported that proteins in rabbit meat represent an abundant source of potential bioactive peptides that could be a suitable material for preparing ACE-inhibitory peptides. Because MYH13 (0.0587 μM^{-1}) and collagen proteins (0.0396–0.0518 μM^{-1}) of rabbit meat had significantly higher ACE inhibitory potential (Chen et al., 2022). Hernández and Zotte (2010) stated that rabbit meat had amino acids that could potentially be as ACE inhibitors. Not only meat proteins but also hydrolysates of rabbit meat protein extracted using trypsin had high ACE inhibitory activity than pepsin and pancreatic enzyme (Permadi et al., 2019). The concentration of inhibitor (IC_{50}) of a peptide should be ranged from 0.32 to 1,000 µM to reduce blood pressure (Panyayai et al., 2018). Chen et al. (2021) detected a novel ACE inhibitory peptide in rabbit meat protein hydrolysate, named ACE inhibitory tetrapeptide Trp-Gly-Ala-Pro (WGAP) which exhibited an ACE inhibition IC_{50} of 140.70±4.51 μM. It apparently says that WGAP in rabbit meat protein hydrolysate had the potential to reduce blood pressure and Chen et al. (2021) proved that 100 mg/kg WGAP significantly reduced systolic and diastolic blood pressure in hypertensive rats by up to 42.66±2.87 and 28.56±2.71 mmHg, respectively, after 4 hours of oral administration. It apparently interprets rabbit meat as a natural source of potent ACE inhibitory peptides and a promising functional food for the treatment of hypertension.

Antioxidant properties

The presence of three enzymes, such as catalase, glutathione peroxide (GSH-Px), and superoxide dismutase have been used to evaluate the antioxidant properties of meat (Ighodaro and Akinloye, 2018). Both catalase and GSH-Px break down hydrogen peroxide into harmless molecules, including oxygen and water. Removal of hydrogen peroxide by catalase enzyme inhibits lipid oxidation in stored meats, and GSH-Px has an excellent ability to reduce a large number of hydrogen peroxide processes (Decker and Xu, 1998). Hernández et al. (2002) stated the activity of GSH-Px in rabbit meat was good enough to control lipid oxidation compared to chicken, beef, and pork. Nonetheless, GSH-Px becomes less stable in refrigerator storage than catalase enzyme. The concentration of antioxidant enzymes including GSH-Px, superoxide dismutase, and aspartate aminotransferase were increased in rabbit hind limb fed with fermented Hybrid pennisetum silage with *Lactobacillus plantarum* and *Pediococcus acidilactici* (Shah et al., 2020). These findings demonstrated that the direct antioxidant properties of rabbit meat are very limited and intentionally manipulated by feeding feed additives and vitamin supplementations. Therefore, further studies are required to provide the underlying concept of the direct antioxidant properties of rabbit meat.

Future Perspectives for the Rabbit Meat Industry

Rabbit has more potential for commercial-level meat production as it has a shorter life cycle, and shorter gestation period, produces a large number of progenies, and has more tolerance to changes in environmental conditions. It has a comparatively faster growth rate and achieves about 2–2.5 kg of body weight within 3–4 months but it depends on diet and other management practices. It is noteworthy that well-planned and effective rabbit farming leads to continuous mass production. It helps producers to obtain an adequate quantity of raw meat for further processing. Consequently, it creates a platform for new enterprises and inventors. But the weak point in rabbit production is not having a well-structured distribution channel from suppliers, processors, wholesalers, and retailers to consumers. This has to be overcome in advance, before starting the mass production of rabbits.

Consumer's priority is highly given to convenient meat products as it requires less time for food preparation and consumption, and clean-up (Brunner et al., 2010). But rabbit meat is mainly sold in the form of whole carcasses and cut-ups, less in the form of processed meat products (Petracci and Cavani, 2013). In order to drive the rabbit meat market, it is necessary to introduce a wide range of processed rabbit meat products into the commercial market. Moreover, rabbit meat-based dishes are linked with traditional recipes, take a long preparation time, and needed specific culinary skills to produce authentic attributes (Albonetti et al., 2017), which reduces the interest of consumers to purchase rabbit meat. This issue could be overcome by producing such products in the form of ready-to-cook and ready-to-eat products. Thus, rabbit meat consumption among consumers was expected to increase.

Consumers are unaware about nutritional importance of rabbit meat. Indeed, the nutritional profile of rabbit meat is excellent and also recommended for children by the World Health Organization (WHO) due to its chemical composition

(Cullere and Dalle Zotte, 2018). However, this information has not yet reached a majority of consumers due to a lack of communication. It has to be widespread via proper marketing strategies, such as social networks, advertisements, magazines, and articles. Further, meat processors should design attractive labelling on rabbit meat products highlighting the significance of the products, approved by the WHO, children-oriented products, etc.

Extensive research studies revealed that the oxidative stability of rabbit meat and meat products was enhanced using different herbs and spices, essential oils, and feed additives. However, limited research studies were conducted on other biological activities of rabbit meat and meat products, such as anti-hypertensive, anti-cancer, anti-diabetic, and anti-inflammatory. Carcass and meat qualities were influenced by many factors including genetics, breed, age and weight, management practices, environments, and pre- and post-slaughter conditions. However, the aforementioned factors have not been analyzed in detail to provide a solid conclusion on the meat and carcass qualities of rabbit meat. The recent consumption rate of rabbit meat is comparatively lower than other meat types. Thus, consumer perception regarding the nutritional and functional characteristics of rabbit meat is the initial step to be taken to promote the consumption of rabbit meat and its meat products.

Conflicts of Interest

The authors declare no potential conflicts of interest.

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Author Contributions

Conceptualization: Anand Kumar S, Kim HJ, Jayasena DD, Jo C. Methodology: Anand Kumar S, Kim HJ. Writing - original draft: Anand Kumar S, Kim HJ. Writing - review & editing: Anand Kumar S, Kim HJ, Jayasena DD, Jo C.

Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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