River Buffalo Meat Production and Quality: Sustainability, Productivity, Nutritional and Sensory Properties

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Abstract: One of the most important challenges facing today's society is feeding a growing world population. This review aims to examine the available information to assess the potential of river buffalo as a meat producer with a focus on the sustainability of the supply chain and on meat quality in terms of nutritional and sensory properties. Traditionally, buffalo meat came from old, culled animals in rural agricultural regions where animals were slaughtered at the end of their productive life as dairy or draught animals. Therefore, the meat had low quality. However, when younger animals are used, buffalo meat is generally well appreciated by consumers. Buffaloes can adapt to different production systems and convert poor-quality high fiber feedstuffs into high-quality products, including meat, with a lower degree of competition with human nutrition. In addition, although requiring more land, extensive production systems may have lower environmental impacts due to the low inputs used in the productive process and show higher levels of animal welfare. Although weight gains and dressing percentages are generally lower than in cattle, the meat is characterized by better nutritional properties (low fat and cholesterol contents, high-quality protein, and unsaturated fatty acids). In addition, the use of appropriate production systems might improve its sensory properties. Therefore, buffalo meat may be considered a good option to meet the increasing demand for food for human consumption.

Keywords: River buffalo, meat, rearing systems, sustainability, performance, nutritional quality, sensory properties.

INTRODUCTION

One of the most important challenges facing today's society is feeding 9-10 billion people by 2050, and the United Nations estimates that the world's population will be 10.8 billion by 2080, and 11.2 billion by 2100 [1]. Indeed, food production is the main challenge for both developed and developing countries, most of them with all sorts of problems, including politics and climate change. Among others, these factors severely limit the possibility of obtaining adequate amounts of high-quality foods [2]. Food and Agriculture Organization (FAO) of the United Nations [2, 3] estimates that worldwide food production should increase by 49% by 2050 in order to feed the growing population with changing nutritional habits.

FAO [4] addresses buffaloes as an important but little-studied species. According to FAOSTAT [5], the buffalo population in 2013 was about 194 million, with most animals kept in Asia (97%); whereas, only a minority was in Africa (2%), half of which was in Egypt, and even less in South America (1%), and in Australia and Europe (less than 1%). Currently, the largest populations are located in India, Pakistan, China, Egypt, and Nepal. In particular, over 50% of the world buffalo population and production are in India, which is, therefore, the largest exporter of buffalo meat [6]. Interestingly, in the last two decades, the number of buffaloes in the world increased at a rate of 2% per year [7], unlike other domestic animals such as cattle,

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whose shares decreased from 55 to 52% from 2010 to 2017 [8]. In Asia, traditional ruminants (i.e., cattle, sheep, and goats) supply around 21% of total meat, while buffalo meat accounts for approximately 11.5% [9]. It should be noted that a high percentage of the meat consumed on this continent is provided by small ruminants, such as goats and sheep [10]; however, pork remains the major species for production and consumption, which accounted for 49.05% of the total meat production in 2014. One-fourth of the meat produced in Asia in that year was poultry [11]. At the world level, in 1965, the estimated per capita total meat consumption was 25 kg, whereas in 2018 increased to 43.7 kg with 12, 18, and 45 kg per capita per year in sub-Saharan Africa, Asia, and Latin America, respectively [2]. However, in developed countries such as the USA, Spain, and Australia, meat consumption can reach over 100 kg per capita per year [12].

River buffaloes (*Bubalus bubalis*) can be classified into swamp buffaloes (2n=48), mainly raised in China, Bangladesh, and the Southeast Asian region, and river buffaloes (2n=50), commonly raised in India, Egypt, Middle East, and Italy. The present study focuses on river buffalo, unless differently specified. Some of the positive aspects of buffaloes are their resistance to disease, adaptation to different climatic conditions, ability to digest poor quality grasses, and still express a satisfactory growth rate, which makes these animals versatile [13-18]. Thus, although buffaloes are already raised for meat production in several countries, they

could potentially be farmed much more widely to provide more meat products for human consumption [4]. Consumers prefer a meat product that is safe, convenient, and with optimal nutritional and sensory properties [19]. As for the other livestock species, the main factors affecting buffalo meat quality are the farming system, including feeding, the breed or genetic cross, and the age at slaughter [20-24]. Factors affecting buffalo meat quality and their impacts are summarized in Figure **1**.

Therefore, the objective of this review is to examine the available information in order to assess the potential of river buffalo as a meat producer with a focus on the sustainability of the supply chain and on meat quality, in terms of nutritional and sensory properties.

SUSTAINABILITY OF RIVER BUFFALO MEAT PRODUCTION: A PREREQUISITE

Another FAO's concern about animal-based products is environmental sustainability in terms of carbon footprint. In fact, livestock production accounts for 14.5% of all anthropogenic greenhouse gas (GHG) emissions [25], and beef production, in particular, is charged for 6% of the global GHG emissions [26]. In addition, livestock had a large impact on land degradation and deforestation [27], terrestrial acidification, and eutrophication [28]. Specifically, global emissions (CO_2-eq million tonnes) are: 2,495 for beef cattle; 2,128 for dairy cattle; 668 for swine; 618 for
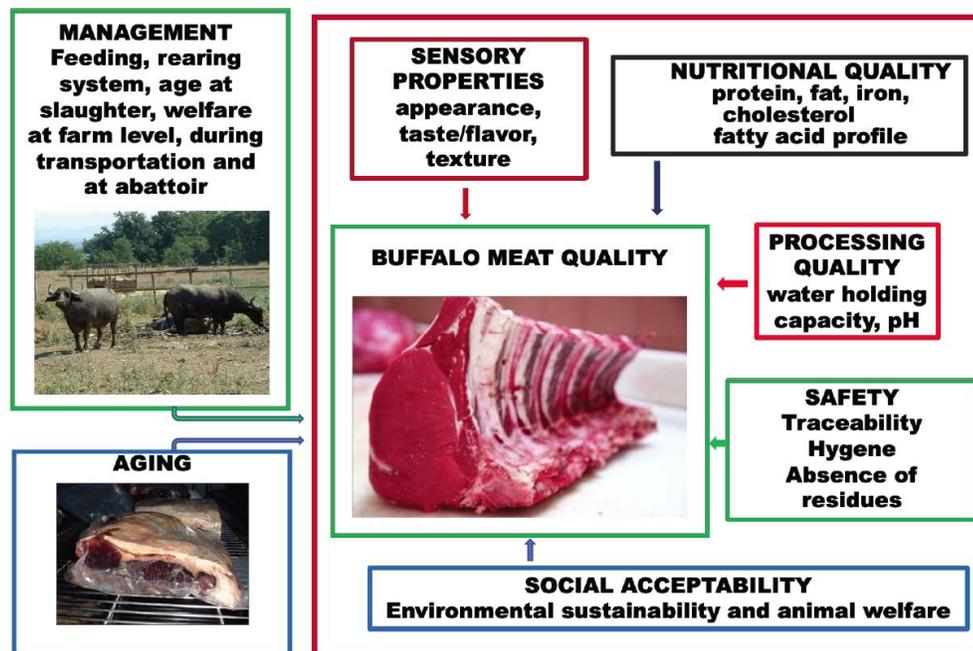

Figure 1: Factors affecting buffalo meat quality.

buffaloes (*Bubalus bubalis*); 612 for chicken; 474 for small ruminants; and 72 for other poultry [3]. Consequently, the global agricultural sector must seek ways to diversify production systems to make them more sustainable and environmentally friendly. However, for the animal-based farms, the identification of best practices, from an environmental point of view, is not simple as different systems often imply trade-offs between different forms of impact. Some systems, such as grass-based systems, although having a higher global warming potential (GWP) and land occupation (LO) compared with the more efficient intensive systems [29-31], may provide some non-commodity outputs and non-marketable public goods services named "ecosystem services" (e.g. provision of clean drinking water, preservation, and enhancement of biodiversity, conservation of cultural landscapes, contribution to the socio-economic viability of many marginal areas, enhancement of meat quality and animal welfare as perceived by consumers) [32, 33] to be considered as additional outputs. Besides, in grass-based systems, there is a lower degree of competition with human nutrition as grazing animals, including buffaloes, can convert vast renewable resources from grassland, pasture, and by-products into food edible for humans; while in intensive systems, feeding is mainly based on cereals, which humans may consume directly. Other studies, [30, 34] showed that grass-finished beef had a higher human-edible protein conversion efficiency compared with grain-finished beef, indicating that the former product yielded more human-edible protein using less human-edible protein inputs.

Similarly, Sabia *et al*. [35] showed that the conduction of part of buffalo farming (i.e., the unproductive phase) on natural pasture allowed the reduction of several sources of pollution, while also reducing the production costs as part of the feed was directly gathered from natural pasture by the animals. In addition, permanent grasslands have an important role in climate stability, as they store nearly as much carbon as forests [36], with 0.01 - 0.3 gross tons of volume C/ year [37], while grazing animals, with their manure, avoid the risk of desertification, improving soil functionality, in terms of structure, organic matter content and resilience to erosion by wind or water. When deposited directly on pastures and fields, manure does not significantly increase the amount of methane [38].

However, grazing should be properly streamlined to avoid excessive ecological damage caused by over-grazing, trampling, soil compaction, and excessive exploitation of water sources [39]. The causes of these impacts can be ascribed to buffalo thermoregulation habits, including wallowing in the mud, especially in periods and areas characterized by hot climates [14, 15, 40, 41]. Future studies should be verified how climate change and the use of shade and swampy areas in hot climates may affect the growth rate, the quality of meat, and the body fat distribution in the river buffalo. Buffaloes need water for thermoregulation purposes. Wallowing represents the natural behavior expression allowing the adaptation to hot climates, which may be monitored based on the changes of the surface temperature in the different body regions through infrared thermography (Figure **2**).

A progressive process of intensification of buffalo farming is currently occurring due to a growing economic interest for this species [17, 18, 41, 42]. As buffaloes often replace cattle in intensive farms, they are handled following the same or similar management routines. However, these conditions expose the animals to new stressors generated by modern technologies (e.g., artificial rearing of calves, reduced space allowances, slatted flooring), widely applied to beef and dairy cattle but unknown to this species [14, 15, 41, 43, 44]. For this reason, ensuring the welfare of buffaloes in different production systems must be considered a key goal. In particular, adequate management (i.e., housing, feeding, and sanitary conditions) should be provided to the animals along with the possibility to express their species-specific behavior because these aspects may have a positive effect on the quality of the final meat product. In addition, the sustainability and welfare of the animals may also affect consumer liking [41].

MEAT PRODUCTION

In the past, buffalo meat was mainly provided by culled animals in rural agricultural regions where animals were slaughtered at the end of their productive lives as dairy or draught animals [45]. Because of their old age and long productive life, they were hardly a good source of high-quality meat (i.e., in terms of safety and sensory characteristics), although their body weight at slaughter was similar to that of cattle [46-49]. In the last decade, in India, 85% of the meat still came from culled animals [50]. For this reason, many consumers consider buffalo meat too dark and tough [51, 49]. However, the Food and Agricultural Organization [4] considers buffalo meat as an important "undervalued" good. In fact, many studies showed that
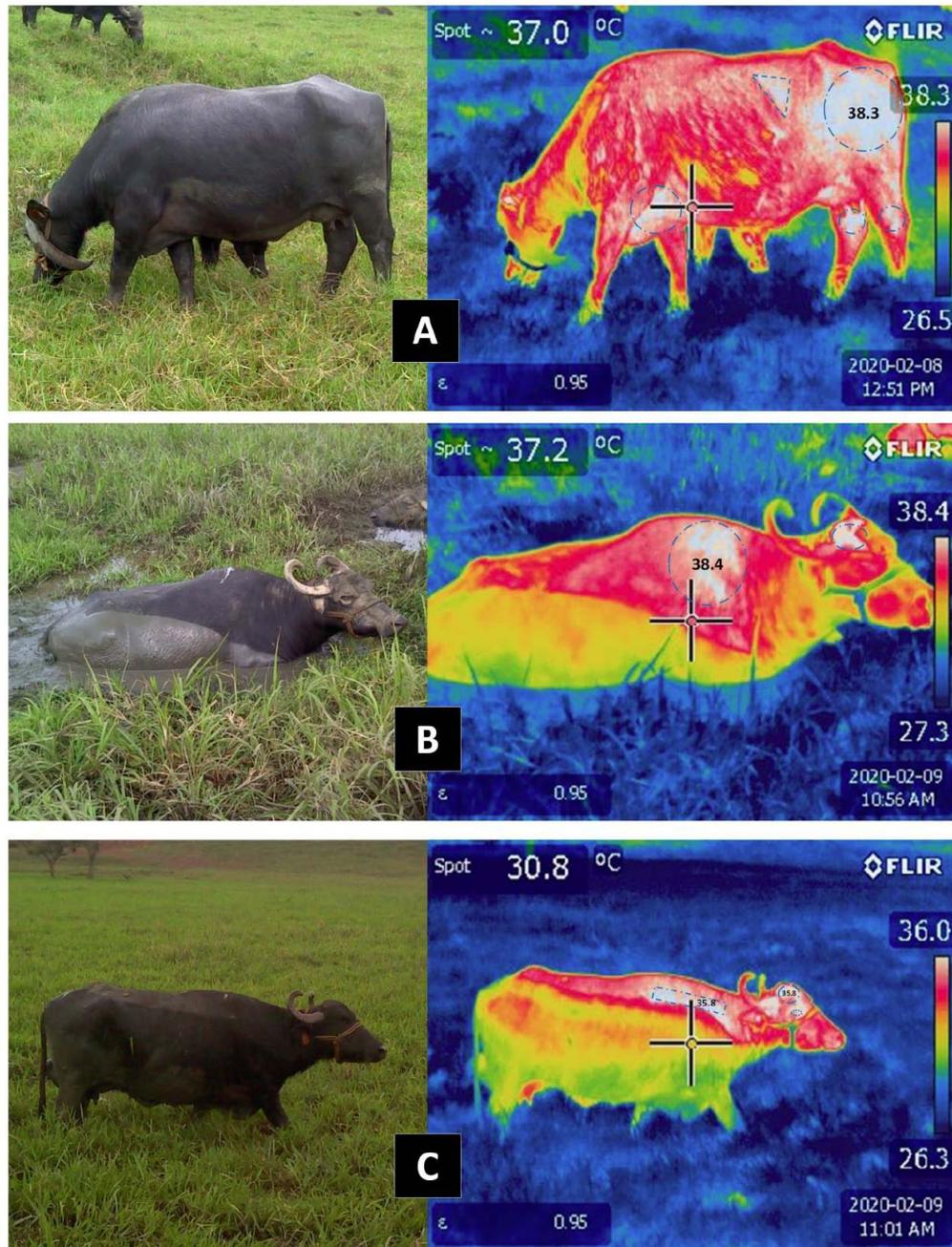
Figure 2: Digital photos and infrared thermographic images of river buffaloes are exposed to the sun without shadow and submerged in the swamp. A) Buffalo in the sun in a tropical region (without shade). The increase in temperature is indicated by reddish coloration in 80 % of the surface of the buffalo. **B**) River buffalo wallowing in the pond with different coloration indicating lower temperature in the submerged region (yellow-green area) and higher temperature in the exposed region (red area). **C**) Muddy Buffalo after leaving the pond with different coloration indicating a lower temperature in the ventrolateral area (yellow-green are). When buffaloes remain in swampy areas, they are properly thermoregulated, thus possibly mitigating any detrimental effects on their performance.

the use of appropriate diets (capable of satisfying their nutritional needs in terms of energy and protein) and a low slaughter age allow obtaining meat comparable with beef cattle in terms of safety, nutritional and sensory properties [14, 47, 48, 52, 53]. Thus, the marketing of buffalo meat should be promoted by using younger animals, establishing quality standards, and by

producing a positive product identity that makes it more attractive to the consumers [51].

Recently, buffalo has become very popular in several countries of Southeast and Middle East Asia, as well as in Africa, at least partly, because of the following reasons: low fat and cholesterol contents,

sensory characteristics similar to beef, no religious prohibitions [49].

Under intensive production conditions, such as those most commonly used in Italy (confinement of the animals, no access to pasture and feeding based on total mixed rations), the lower growth rates and dressing percentages, as compared with cattle, may make uneconomical buffalo meat production, unless a premium price is paid for this product. Buffalo meat production is well accepted and competitive in the Brazilian Amazon region mainly because of well-planned and implemented production procedures that combine silvopastoral and intensive rotational pasture-based systems [54, 55]. Unfortunately, there are no quality-based schemes in Brazil, and buffalo meat is frequently unfairly priced in relation to its high nutritional value [42, 54].

Therefore, an appropriate commercial marketing strategy for products derived from the buffalo should be developed based on the positive characteristics of meat [56]. Additional market opportunities may derive from the technological properties of buffalo meat, which can be conveniently processed into ready-to-eat [47, 48] or other high-quality transformed meat products [57].

The phenotypical characteristics of river buffalo allow the adaption to different production systems, including extensive conditions in tropical areas, where poor-quality feeds with high fiber content are available while animals are exposed to a variety of diseases and parasites [58], and intensive conditions where high protein and energy diets are usually fed [59].

In harsh, tropical environments, when low input diets are offered, buffaloes grow at a greater rate compared with cattle [60]. This is due to more efficient fiber digestion, which is, in turn, dependent on a longer transition period and the presence of different rumen microorganisms as compared with cattle. This means that buffaloes are better adapted to a high fiber tropical forage diet. As a result, the microbial protein synthesis is more efficient with more efficient use of structural carbohydrates [61].

It has been suggested that buffaloes are highly-efficient in transforming forage with high fiber content because of their intensive bacterial activity, slow rumen movements [13] and lower rumen outflow rate than cattle [62]. However, these advantages tend to disappear when buffaloes are fed high-energy diets [60]. Moreover, the rumen-reticulum and omasum-abomasum are heavier than in cattle (7.38 vs. 4.96 and 3.56 vs. 2.74 kg, respectively), suggesting that this species may have better feed digestion and conversion rates. These factors result in a slower transition of both solids and liquids [63]. In addition, Vega *et al*. [64] reported that the number of buffalo mastication movements is lower than in cattle because of the wider diameter of pterygoid and masseter muscles and tongue, thus suggesting a greater chewing strength and a more efficient ruminating process.

In intensive systems, the benefits consist of improved carcasses quality and meat availability throughout the year as compared with extensive systems [51]. This latter positive aspect can be achieved by using the out of season breeding technique.

Borghese [65] reviewed several studies comparing the growth and performances of dairy cattle and buffaloes receiving the same diets. In general, buffaloes showed lower weight gains and dressing percentages. In particular, the weight gains were slightly below 1.00 kg per day for Mediterranean, Jafarabadi, and Murrah buffaloes, whereas dressing percentage was about 53.3%, thus below the values shown by Friesian, Angus, and Hereford cattle (58.4, 63.3 and 62.1%, respectively) fed the same diet and slaughtered at about 24 months. The dressing percentage can be even less in buffalo heifers with values below 50%. The low dressing percentage values observed in buffaloes can be attributed to the high incidence of the head (including horns), skin, and hooves. Conversely, the percentage of meat in the carcass was generally higher in Mediterranean buffaloes than cattle [66]. Subcutaneous adipose tissue content was higher in buffaloes, whereas the inter- and intramuscular adipose tissues were higher in cattle. Due to the rapid reduction in growth and consequent increment of the feed conversion ratio, a maximum slaughter weight of 450 kg was suggested for Mediterranean buffaloes. More recently, Masucci *et al*. [59] obtained similar results in intact Mediterranean buffalo bulls slaughtered at about 490 kg with weight gains ranging between 0.89 and 0.93 kg/d and dressing percentages ranging between 50.2% and 51.6%. The same authors detected no differences in weight gains and dressing percentage between two groups of animals fed iso-nitrogenous and iso-caloric diets with different levels of maize silage in the ration.

Li *et al*. [67] studied groups of Binlangjang buffaloes (China's only species of river buffalo) at different ages.

Figure 3: River buffalo in confinement (Feedlot period). The main factors affecting buffalo meat quality are the farming system, including feeding, the breed or genetic cross, and the age at slaughter.

These authors evaluated the dressing percentage and physicochemical properties of the *Longissimus dorsi* and *Biceps femoral* muscles. The dressing percentage and quality of male buffalo meat were obviously affected by age. The dressing percentage decreased from 54.9% in young to 51.2% in older animals, though meat percentage and carcass meat yield increased (34.58 *vs.* 38.59% and 62.95% *vs.* 75.34%, respectively). Marbling, backfat thickness, and rib-eye fat also increased with age. The authors concluded that at 24 months of age, Binlangjang buffaloes had a higher dressing percentage and improved meat quality.

NUTRITIONAL QUALITY

Buffalo meat may provide health benefits over beef [68], due to its composition, nutritional, and functional properties [69]. In particular, meat obtained in good management conditions may have a better nutritional quality than beef (Table **1**) with lower total lipids (1.37g), saturated fatty acids (0.460 g), and monounsaturated fatty acids (0.420 g) in comparison with beef (10.19 g, 4.330 g, 4.380 g respectively) [49].

In the Philippines Lapitan *et al*. [80, 81] observed that the performance of Brahman crossbred cattle and crossbred river buffaloes was comparable in terms of growth, carcass, and meat quality. The two groups of animals had the same age at the slaughter and received the same fattening diet (corn silage, brewer grains and concentrate). Similar results about buffalo

meat composition, nutritional and functional properties were found by Anjaneyulu *et al*. [69]. The buffalo carcass has a different fat distribution than cattle carcass with a prevalence of subcutaneous fat and few infiltrations in the muscular tissue (typical marbling of the meat). This means that, at the time of consumption, fat can be easily detached from the lean part with less total lipid content as compared with most beef cattle (Table **1**). Conversely, buffalo meat is similar to that of local beef cattle breeds, which are leaner [78]: cuts from 2-year-old male buffalo calves have a fat percentage of only 1.0 to 3.5/100 g [82]. As a consequence of the lower fat content, the energy value of buffalo meat is 57% lower than beef with a mean energy value of 6.8 Kcal/g of dried meat [80]. Buffalo meat also has a lower cholesterol concentration than beef, which is generally below 50 mg/100 g (Table **1**) and a lower fat saturation compared with beef [82]. In particular, the low contents of myristic and palmitic acids lead to low atherogenic and thrombogenic indexes [47, 58, 65, 83]. As a possible consequence, Giordano *et al*. [84] observed that partial substitution of beef with buffalo meat in the diet of 300 consumers determined a marked reduction of plasma cholesterol and triglycerides concentrations, less pulse wave velocity, and a reduced response to oxidative stress.

Joel *et al*. [54] evaluated two buffalo production systems in Brazil: a traditional extensive livestock system, where low daily weight gains were achieved, and a mixed system, where at weaning, the buffalo

Table 1:　**Chemical and Physical Characteristics of River Buffalo Meat Compared with Beef [21, 22, 48, 54-70]**

	River buffalo	Aberdeen Angus	Charolais	Limousin	Hereford	Podolian
Dry-matter (%)	20.6-25.0[1,2,3]	25.8[5]	25.0[5]	24.8[8]	26.3[5]	25.6[12]
Protein (%)	21.2-21.6[1,2,3,4]	20.6[5]	21.2[5]	21.4[8]	21.1[5]	22.6[12]
Fat (%)	1.2-2.3[1,2,3]	3.4[5]	2.4[5]	2.1[8]	3.4[5]	1.6[12]
Ash (%)	0.72-1.6[1,2,3]	1.0[5]	1.0[5]	1.0[8]	0.9[5]	1.1[12]
Cholesterol (mg/100g)	32.4-49.0[1,2]	68.0[5]	63[5]	50.9[9]	65[5]	52.3[13]
Saturated FA (%)	48.3-55.7[1,3]	51.4[5]	53.3[5]	49.3[10]	50.7[5]	47.0[13]
Monounsaturated FA (%)	34.4-40.6[1,2,3]	38.5[5]	35.3[5]	28.4[10]	39.6[5]	36.7[13]
Polyunsaturated FA (%)	14.8-17.2[1]	7.4[5]	8.3[5]	22.3[10]	7.2[5]	16.3[13]
Polysaturated	0.3-0.4[1]	0.1[5]	0.2[5]	0.4[10]	0.1[5]	0.3[13]
n6/n3 Fatty Acids	5.9-7.1[1,2,3]	4.2[5]	7.1[5]	2.6[10]	5.2[5]	14[13]
pH	5.5-5.7[1,2,3,4]	5.7[6]	5.6[7]	5.6[8]	5.6[9]	5.6[14]
L*	34.0-44.1[1,3]	36.7[6]	46.1[7]	36.2[8]	41[11]	37.7[14]
a*	15.3-18.2[1,3]	20.8[6]	11.6[7]	22.7[8]	27.8[11]	18.7[14]
b*	12.6-15.8[1,3]	0.8[6]	11.3[7]	6.5[8]	10.4[11]	4.7[14]

[1]Cifuni *et al*. [22]; [2]Calabrò *et al*. [21]; [3]Joele *et al*. [54];[4]Kandeepan *et al*. [48]; [5]Bureš *et al*. [71]; [6]Wolf *et al*. [72]; [7]Bureš *et al*. [73]; [8]Pesonen *et al*. [74]; [9]Brugiapaglia *et al*. [75]; [10]Malau-Aduli *et al*. [76]; [11]Huuskonen *et al*. [77]; [12]Marino *et al*. [78]; [13]Braghieri *et al*. [79]; [14]Marino *et al*. [70].

calves were moved from the traditional extensive livestock to an intensive rotational grazing system, with feed supplementation and a higher stocking density. Meat from Murrah × Mediterranean buffaloes (*Bubalus bubalis*), aged 36 months, with an average body weight of 450 kg and reared in the mixed system contained less myristic acid (C14:0) and a less $\omega 6: \omega 3$ fatty acid ratio, both beneficial to human health. However, in the traditional system a higher poly-unsaturated fatty acid content was obtained. In raw buffalo meat, the most abundant fatty acids are oleic, stearic, and palmitic acids, but the cooking method can affect the fatty acid profile with reduced percentages of palmitic and myristic acids in fried meat. However, higher concentrations of trans fatty acids were detected in fried samples [85].

Buffalo meat represents a good source of protein (Table **1**), particularly young animals, with an amino acid profile similar to that of beef [86]. As for protein content and quality, Landi *et al*. [87] observed that river buffalo meat had a protein content higher than beef (21.13 g/100 g and 19.23 g/100 g, respectively), with an amount of essential amino acids ranging from 8.52 to 10.36 mg/100 g. Genetic analysis on buffaloes and cattle, in fact, showed that buffaloes have a high expression of genes involved in the homeostasis of iron, cholesterol, and other lipids, which confers their meat a high protein and a low lipid content [88]. Buffalo meat had a more intense color than beef, but the latter

had a lower protein, higher fat, and ether extracts content. The more intense color of buffalo meat was due to the greater amount of myoglobin contained in muscles [88] and, consequently, to a higher amount of iron (1.4 mg/100 g vs. 1.2 mg/100 g) [89].

SENSORY PROPERTIES

The texture characteristic of foods constitutes one of the main sensory inputs perceived by consumers [90]. Texture derives from the structure of food and the way ingredients interact [91]. A number of studies showed that tenderness is the main attribute affecting consumers' preferences for meat, regardless of domestic or wild animal species, beef [92], pork [93] or venison [94], followed by juiciness and flavor, including a less-fatty taste and texture [92].

Multiple factors contribute to differences in tenderness between different muscles such as post-mortem proteolysis, intramuscular fat, connective tissue, and contractile state of the muscle [95]. Inadequate tenderness is the most frequent motivation of consumer dissatisfaction, so any improvement in this parameter would increase the value of the final product [96]. During the transformation of muscle into the meat, μ-calpain is activated; this is an enzyme having a major role in the post-mortem proteolysis during meat aging [97. In fact, during aging, muscles undergo a series of physical and biochemical changes responsible for their

conversion to meat; in particular, these modifications concern the Z-disk weakening and the myofibrillar proteins (and other associated proteins) [98]. As to aging, Rajagopal and Oommen [99] found that the intensity for overall tenderness increased by 13.3% after 8 d of aging compared with 1 d aged buffalo meat.

Kandeepan *et al*. [47] studied the effect of gender and age on the sensory properties of pressure-cooked meat chunks. They observed that appearance, flavor, and juiciness scores were not significantly affected by these factors, whereas tenderness differed significantly among young males, culled male and culled female buffalo groups, with greater values for the first group.

Andrighetto-Canozzi *et al*. [100] analyzed the sensory properties of meat from castrated Murrah buffaloes with an initial average age of 15 months, slaughtered at 75, 100, 125, or 150 days of the feedlot. The authors concluded that the confinement time did not influence the physicochemical and sensory characteristics of the meat of young Murrah buffaloes.

CONCLUSION AND APPLICATIONS

Given that buffaloes can adapt to different environmental and rearing conditions, extensive buffalo farming seems to be more environmental and animal friendly due to the lower levels of GHG emissions, the higher levels of welfare, and a lower degree of competition with human nutrition observed in this system.

The critical points of intensive and extensive systems are different. Therefore, meat production can be improved in qualitative and quantitative terms in both extensive and intensive systems, and, for this reason, it is essential to maintain a balance between welfare and productivity.

The age of the buffalo at slaughter is a key factor in meat quality. Although carcasses of young buffaloes are characterized by a lean conformation and thin, fat cover, slaughtering at 24 months of age is recommended for extensively reared animals in order to obtain high-quality meat. The inclusion of feed supplements and concentrate feedstuffs in the rations when raising young animals may improve carcass quality, dressing percentage, and several physicochemical characteristics of the meat. Conversely, in intensive systems where feeding is based on more concentrated feeds, an age of about 16 months seems to be appropriate to maximize the efficiency of the transformation of feed into meat.

The desirable qualitative characteristics of buffalo meat are high tenderness and water-holding capacity, and moderate myofibrillar fragmentation index. In addition, the darker color of buffalo meat compared to beef may be considered a distinctive feature, indicating higher iron availability. From a nutritional point of view, buffalo meat shows high protein contents, a well-balanced amino acid profile, and low cholesterol and lipid levels. The fatty acid profile is low in saturated fatty acids and high in monounsaturated fatty acids, with presumably favorable effects on human health. Buffalo meat is also suitable for the production of ready-to-eat and other processed meat products. It has also gained greater popularity in several countries in Southeast and Middle East Asia, Latin-America, and Africa because there are no religious restrictions concerning the consumption of buffalo meat.

We conclude that buffalo meat may represent a good option to meet the increasing demand for food with high essential protein and low-fat content for human consumption.

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