Scientific Findings on the Quality of River Buffalo Meat and Prospects for Future Studies

Rosy Cruz-Monterrosa[1], Daniel Mota-Rojas[2,*], Efren Ramirez-Bribiesca[3], Patricia Mora-Medina[4] and Isabel Guerrero-Legarreta[5]

[1]*Department of Food Science, Universidad Autónoma Metropolitana (UAM), Lerma Campus, Lerma City, 52005, Mexico*

[2]*Neurophysiology, Behaviour and Animal Welfare Assessment, DPAA, Universidad Autónoma Metropolitana (UAM), Xochimilco Campus, Mexico City, 04960, Mexico*

[3]*Livestock Production, Colegio de Postgraduados, Montecillo, 56230, Texcoco, México*

[4]*Livestock Science Department, Universidad Nacional Autónoma de México (UNAM), Facultad de Estudios Superiores Cuautitlán, State of Mexico, 54714, Mexico*

[5]*Emeritus Professor, Universidad Autónoma Metropolitana (UAM) Iztapalapa Campus, Department of Biotechnology, Food Science, Mexico City, 09340, Mexico*

Abstract: The objectives of this review are to detect scientific findings and areas of opportunity in the study of river buffalo meat from primary production through commercialization and to establish future areas of research linked to each step of the meat supply chain to strengthen and improve the production and quality of buffalo meat in the future. Recent studies show that buffalo meat is healthy and that the prevalence of cardiovascular and cerebrovascular diseases is not related to intramuscular fat consumption. The current grand demand for food constitutes an ongoing challenge for agricultural production. Of course, this demand includes meat, but the animal species traditionally destined for human consumption are no longer capable of satisfying requirements. This review detected gaps in studies of the alimentary systems of this species (including its digestive tract) and a paucity of analyses designed to determine the optimum slaughtering age. Identifying –and correcting– practices that foster contamination, reduce the shelf life of buffalo meat, and suggest appropriate conservation and packaging methods during commercialization are two additional pending concerns. This study concludes that marketing buffalo meat represents a great challenge for producers and researchers, one that requires a multi- and interdisciplinary approach that examines in detail every step of the productive chain.

Keywords: *Bubalus bubalis*, sensory analysis, food safety, nutritional, healthy, human consumption, conservation, packaging, authenticity.

INTRODUCTION

The buffalo meat is an excellent healthy alternative compared to beef [1]. More scientific studies are required to confirm these results and affirm this statement from the organoleptic and economic point of view to spread the consumption of buffalo meat in the diet of millions of people worldwide. Satisfying current demand for food is a constant challenge due to population growth and nutritional requirements of human being, in the near future, to feed the 8 billion people that the United Nations Food and Agriculture Organization (FAO) predicts for the year 2030, coupled with an anticipated increase in *per capita* consumption. Meat is one of the foods that provide high nutritional quality in terms of balanced nutrients, and that consumption is expected to increase in developed countries at an annual rate of 2.1% [2]. This situation makes it essential to understand that the agricultural sector is facing a new challenge: how to increase meat production while simultaneously improving quality. Under existing conditions, traditional livestock systems will be unable to satisfy this huge population's demand for meat, so it will be necessary to turn to new animal species that have better productive performance and higher yields, but without ignoring the nutritional quality of the meat produced [3-7]. One emerging option with areas of opportunity for meeting this alimentary challenge is river buffalo meat.

Buffalo meat is a red meat alternative with great opportunities for success [8]. Comparisons of buffalo meat to traditional beef products have found that its characteristics are competitive; for example, although in physicochemical terms, river buffalo meat has a redder color, its protein content is higher than that of beef [6, 7, 9]. Its content of polyunsaturated fats may help reduce risks to human health [7, 10].

Enzymatic, physical, and chemical methods have been used by scientists to minimize the variation in the

*Address correspondence to this author at the Neurophysiology, Behavior and Animal Welfare Assessment, Universidad Autónoma Metropolitana (UAM), Calzada del Hueso 1100, Del. Coyoacan, 04960, Mexico City, Mexico;
E-mails: dmota@correo.xoc.uam.mx, dmota100@yahoo.com.mx

tenderness of buffalo meat and to guarantee uniform quality [11, 12].

Recent scientific advances in the structural properties such as histochemical and physicochemical quality of buffalo meat have been recently studied [12, 13]; however, scientific advances comparing the variation in meat quality of river buffalo are scarce. River buffalo meat is tenderer than beef from crossbreeds of *Bos Indicus* [6-8, 14]. However, questions continue to surround the benefits of buffaloes raised to supply meat and the nutritional, physicochemical, and sanitary characteristics of these products [1, 4, 5, 15]. According to the studies carried out by Kiran *et al*. [15], it is necessary to continue with tenderization strategies that reduce the variation between tough and tender *Bubalus bubalis*' muscles. Against this background, our review aims to identify perspectives for the study of buffalo meat from primary production through commercialization, including comparing the traditional livestock-raising systems that predominate in Asian countries to the more intensive systems based on induced grazing and feedlots that have emerged in Europe and the Americas. In addition, it describes areas of opportunity in the study of river buffalo meat production and suggests potentially important areas of research related to distinct production units based on exchanging experiences with the cattle sector, as a way to strengthen and enhance the production and quality of river buffalo meat in the future. The approach adopted examines all steps of the commercialization process and the characteristics of river buffalo meat, including nutritional, sanitary, and commercial aspects. Finally, it addresses the reality that, as a high-quality/high-value product, buffalo meat is susceptible to fraudulent practices, and outlines methodologies that can potentially be used to validate its authenticity (Figure **1**).

THE RIVER BUFFALO WORLDWIDE

The current world population of buffaloes is around 205 million, with 92.5% concentrated in Asia [16]. Countrywise population, 80%, is located in India and Pakistan [16], two nations producing 78.5% of all buffalo meat in the world. India is considered the principal exporter of buffalo meat on the planet, which provides attractive incentives for the small ranchers who raise these animals. However, while India is the largest producer of river buffaloes, its production systems are far from uniform. This reality can be traced back to the fact that before becoming an important meat-producing species, the buffalo was the key draft animal in Asian agriculture [17], and they are still used in such field labors as plowing, leveling land, crop harvesting and cultivating plants like rice, as well as in traction work that involves transporting people and goods, pumping water, drawing wagons, and pulling boats in shallow waters [5, 6, 15, 18].

Due to its anatomophysiological characteristics [19], the buffalo is well-adapted to humid or marshy regions [20], so they enjoy a comparative advantage over traditional cattle in these environs, though this does not

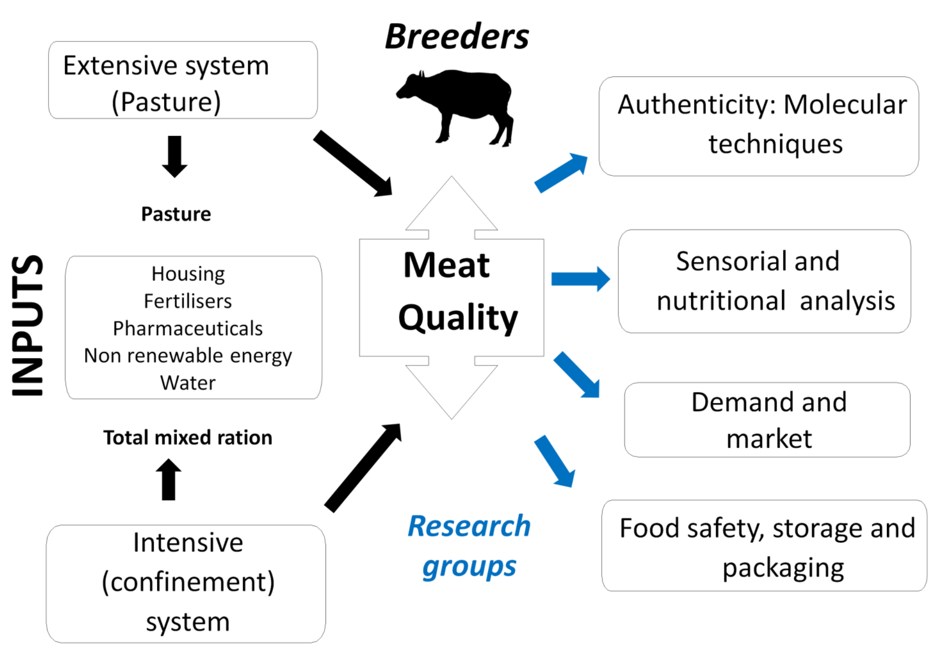

Figure 1: Perspectives for studies of river buffalo meat.

imply that they are immune to the diseases typical of these regions and environmental conditions, also if it gets used to handling and good treat, this large ruminant will allow an excellent human-animal relationship [4, 5, 21-24]. Gujarati buffaloes, for example, require a program of preventive medicine and sanitary handling similar to those used with cattle because they are susceptible to hemoparasites like the tick *Rhipicephalus* [25, 26]. River buffaloes are rustic animals usually raised in conditions where they ingest natural pastures, agricultural byproducts, and some supplements at critical stages, but whose alimentary management is not oriented exclusively towards producing calf meat [4, 27-29]. Additionally, river buffalo's thermal balance through high-tech infrared thermography facing extreme climates in the tropics of the Americas is being studied [22, 24, 30]. At the planetary level, only a few countries –Australia, New Zealand, and a few in Europe and the Americas– have adapted the buffalo to intensive production systems with induced pasturelands or conditions of confinement [31-33]) designed to produce meat and milk [21].

While studies have explored the advantages and disadvantages of intensive [34] *vs*. extensive [35] systems with respect to the productive performance of the river buffalo in terms of both meat and milk, additional scientific research is required, including studies of economic viability, market research to identify the best production practices, and analyses of the most attractive channels for commercializing buffalo milk and meat, all of which will provide important feedback to primary producers [4, 5].

FEEDING AND RUMINAL BIOCHEMISTRY

The primary raw materials required for livestock production are feed and the mechanisms that allow animals to optimize nutrients and transform muscle into meat [36]. Compared to cattle, the river buffalo has a much higher capacity to degrade fibrous forage, such as straw and sugarcane residues, so this species can produce meat and milk from the residues of both cultivated fields and open pastures [4, 5]. While the efficiency of buffalo production may be low, but it is economically viable. In general terms, studies state that buffaloes require 0.24 kg of digestible protein, 1.8 kg of TDN, 6.6 MCal ME, 14 g of Ca, and 11 g of P [37]. The balanced rations that have been given *ad libitum* to buffaloes have included as much as 75% of concentrate [37]. Growth rates depend on breed, production system, and diet quality; for example, reports have found a weight gain of 610 g day^{-1} with an alimentary efficiency of 7:1 based on integral rations that include a minimum of 50% of concentrate [38], or gains of 370 g day^{-1} with an alimentary efficiency of 10:1 when providing rations that include *Trifolium alexandrinum* (berseem) [13]. As is true for the alimentation of all ruminants, the key nutrients that influence carcass and meat quality are proteins and energy foods. The level of biomolecules provided by food depends on the availability and the production system; for instance, ruminants fed byproducts, and poor-quality pasture will have low yields as dressing carcasses compared to animals fattened with high-quality pastures or those raised under conditions of confinement. In addition, the amounts of energy and protein provided in the diet impact meat tenderness, due to their effects on intramuscular fat content and polyunsaturated fatty acid (PUFA) profiles [39]. This means that intensive production systems are the best option from the purely nutritional perspective since these profiles and the percentage of fatty acids in the diet can be modified to improve meat quality. But much additional research is necessary to determine suitable profiles for each breed of buffalo and provide orientation as to the optimal feeding regimens for ensuring the nutritional and instrumental quality of buffalo meat.

While existing alimentary manuals for ruminants – for example, the National Research Council (NRC) stipulate the nutritional needs of animals in relation to weight, age, workload, and reproductive stage, specific requirements for buffaloes have not been studied sufficiently, as shown by the fact that the current alimentary requirements of the river buffalo are based on the NRC's for cattle [40, 41], though without doubt, the specific characteristics of the buffalo's digestive system entail nutritional needs distinct from those of cattle. To cite one example, the requirement of metabolizable protein differs between these two species because the microbial mass of the buffalo's rumen is more effective than in cattle, so the parameters of ruminal fermentation differ [42, 43]. A study of Nili Ravi buffalo calves less than one-year-old suggests that the diet contains 14.2% of protein and 2.24 Mcal / kg of ME [37]. This is because the low weight gain in growing buffalo calves may be the consequence of a nutritional imbalance in traditional feeding systems.

The populations of certain species of bacteria and protozoans in the rumen are higher in buffaloes than cattle under diverse conditions of alimentation [44]. We also know that there is an association between the amino acids of the microbial protein and the amino acids in muscular tissue (a correlation of 0.83, P<0.003) [40], so we can assume that the buffalo is a more efficient provider of symbiotic microbial protein and, therefore, produces meat with better protein content. This opens an area of opportunity for research because this physiological event has not been quantified for this species. With respect to the amount and quality of fatty acids in buffalo meat, the scientific information currently available is insufficient to support the use of certain supplements that contain fats or oils, or the amounts of polyunsaturated fatty acids in the diets given to buffaloes, which could orient producers regarding the quantification of polyunsaturated fatty acids and the formation of conjugated linoleic acid in buffalo meat.

NUTRITIONAL AND SENSORY ANALYSIS

Recent studies show that buffalo meat is healthy and that the prevalence of cardiovascular and cerebrovascular diseases is not related to the consumption of intramuscular fat [1]. People involved in producing and commercializing buffalo meat sustain that it is better than beef, emphasizing that since it is richer in proteins and contains less fat and cholesterol, it lowers the risk of cardiovascular and atherosclerotic damage in humans who consume it [13, 45]. Buffalo meat can satisfy women's requirements since it has adequate content of B-complex vitamins, Zn, and cholesterol [46]. River buffalo meat has advantages for human consumption since it has a higher protein (21.13g / 100g) compared to beef (19.23g / 100g) [47]. This was verified by Landi *et al*. [48], who analyzed meat of the *Longissimus dorsi* muscle of male buffaloes from the Campania region in Italy. Tamburrano *et al*. [1] recently demonstrated that in different organoleptic parameters, Italian Mediterranean buffalo meat is superior in many nutritional and dietary characteristics compared to beef. However, as with all species of an animal destined for human consumption, we know that meat quality depends on various factors on the farm: the type of production system, the kind of alimentation, inherent characteristics of the animals such as genetics, age, sex, and breed, and even ante-mortem handling [49]. Due to the nature of the predominant production system, buffaloes are general thinner and contain less subcutaneous fat than cattle. In addition, the meat of older animals has poor flavor compared to that of young animals (16-20 months), who produce lean, tender meat with less fat. The fat content of buffalo meat has a whitish-to-yellowish color due to beta-carotene content [38], but no study has found differences in pigment content between buffaloes and cattle raised in similar production systems. Several comparative studies of buffalo meat *versus* beef have been conducted, but they do not include detailed descriptions of the production systems under which the study animals were raised.

As mentioned above, buffalo-raising operations largely employ a traditional system characterized by low levels of technification. This makes it difficult to determine whether the river buffalo's productive performance and the quality of its meat are comparatively better than those of traditional cattle. Some studies designed to compare and evaluate buffalo and cattle production have been conducted, but only under the conditions of confinement systems [6, 7]. While this research has obtained important conclusions, it is important to understand that systems of this kind are rarely found in regions devoted to raising buffaloes. However, one important contribution of such studies is that they provide precise data on the quality of the meat produced by both species. One such study was conducted by a group [45] that compared the qualitative characteristics of the *longissimus* muscle of Murrah buffaloes, and young Nellore steers at an average age of 21 months that were raised under conditions of confinement for 3.5 months. They found that, compared to the cattle carcasses, those of the buffalo obtained better results in terms of yield (dressing carcass) at 57.2 *vs*. 52.1%, had a better fat covering (13.8 *vs.* 8.1 mm) which meant less drip loss (1.3% *vs.* 1.8%) and better cooking performance (29.42 *vs.* 31.31%). Additional characteristics were lower collagen content (4.81 *vs.* 5.73%), and higher moisture content (75.13 *vs.* 74.55%).

Regarding tenderness and the proportion of omega-6 fatty acids, omega-3 levels were similar in both species. Finally, the buffalo carcasses had better yields in terms of the cuts with higher commercial value. Meanwhile, the cattle carcasses had higher amounts of C12:0 and C14:0 meat related to the increase of lipoproteins and cholesterol, but the buffalo meat was higher in C18:0 and C18:1n9c. It is important to point out that the latter fatty acid is associated with preventing cardiovascular disease in humans. With respect to conjugated linoleic acid (considered potentially beneficial for human health), studies are insufficient to determine concentrations in the meat of these two species [45].

In terms of lipids, in buffalo meat these are deposited largely between the muscles –in contrast to cattle– so it is not characterized by marbling, and tends to have a more intense red color than beef [50, 51]. A slight variation in myoglobin concentration occurs in older buffaloes that give a gold tinge to their meat [52]. The amount of saturated fats and the content of polyunsaturated fatty acids (PUFA) were higher in buffalo meat and lower in beef, though lipid oxidation is greater in the *longissimus* muscle of buffaloes than in beef. The higher malonaldehyde profile indicates the decomposition of the PUFA that can deteriorate the flavor, color, aroma, and nutritional value of meat [53]. Moreover, peroxides and products of secondary oxidation can form free radicals, though it seems that the process of oxidation in buffalo meat may be associated with higher amounts of iron ions and myoglobin [54]. Possible areas for future research should include studying ruminal biohydrogenation in buffaloes and the administration of antioxidants in their diets, or their direct application to prolong shelf-life and maintain, or perhaps enhance, the nutritional quality of the meat.

Other research on the quality of buffalo meat indicates few differences in the amount of calpastatin (a natural inhibitor of the protease calpain) and calpain 1, 2 activity, though this also requires additional study because of their essential role in transforming muscle into the meat and their effect on meat tenderness [55]. With respect to the histological characteristics of the muscle mass of buffaloes, Nuraini *et al*. [56] found that the diameter of muscle fiber is affected by age. At 1.5 years of age, this diameter is 37.37 µm, but in buffaloes, over 3 years old, it increases to around 55 µm. In contrast, none of the following properties are affected by the sex or age of buffaloes: diameter of the fascicule, the thickness of connective tissue, pH, loss during cooking, and water-holding capacity [56]. Differences in these variables may be determined as a result of the morphological and metabolic changes that occur as animals mature and approach old age, but studies designed to determine specific effects on tenderness and the instrumental quality of buffalo meat are needed.

FOOD SAFETY, SHELF-LIFE AND PACKAGING

Meat and meat products are among the most susceptible to decomposition because they offer ideal conditions for the growth of harmful microorganisms and can mask contamination by pathogens that cause disease in consumers. The processes of microbial contamination in fresh meat begin with hygiene practices at production units and continue through the transport, slaughtering, butchering, and packaging of the meat. The most common microorganisms that contaminate meat, regardless of the animal species involved, are those of the intestinal and respiratory tracts, the ones found in fecal matter, and others that thrive in abattoirs and other meat-processing sites. The latter include *Pseudomonas*, *Acinetobacter*, *Brochothrix thermosphacta* [57, 58], *Clostridium* species, *Carnobacterium* spp., *Leuconostoc carnosum*, *Leuconostoc gelidum*, Lactobacillus sake, Lactobacillus *curvatus*, and the atypical or unidentifiable lactobacilli *Brochothrix thermosphacta, Enterococcus* spp., *Serratia liquefaciens*, *Hafnia* spp., *Proteus* spp., and others of the *Enterobacteriaceae* family [59]. Besides, molds and yeasts can alter the innocuity of meat [57]. Reducing these contaminants requires applying lactic acid at 2-4% to buffalo carcasses to diminish the aerobic microbial load without affecting the sensory attributes of flavor and aroma or the general acceptability of the fresh meat [60].

The conservation and packaging of buffalo meat or any species, for that matter– are high-priority processes that must be performed adequately to maintain innocuity and the visual characteristics that attract consumers. The first step consists of evaluating the color and general appearance of the meat as packaged. After removing the packaging material, the variables of texture, aroma, and flavor can be assessed. The microbiological profile is one of the key criteria for determining the quality and safety of fresh products, including meat. The bacterial pathogens identified most frequently in meat and meat products are *Salmonella sp., Campylobacter, Clostridium perfringens, Staphylococcus aureus*, and *Escherichia coli* O157: H7. Less frequent contaminants are *Pseudomonas sp*., *Listeria monocytogenes, Yersinia enterocolitica,* *Bacillus cereus*, and *Vibrio parahaemolyticus* [61, 62]. With specific reference to river buffalo meat, the following quantify coliform bacteria have been identified: *Staphylococcus spp*. (mainly in Indonesia; [38]), and *Campylobacter spp.* The presence of the latter may occur through cross-contamination during evisceration due to deficient hygiene techniques during carcass cutting, deboning, and transport to butcher shops where meats of various species may be sold. *Campylobacter jejuni* is the pathogen with the highest prevalence in meat [63]. The World Health Organization (WHO) recommends vaccination and antimicrobial treatments to reduce their presence.

Various Asian and Latin American countries have severe problems of diarrheas in human populations that are attributable to poor production practices. There, both water buffalo meat and beef have been identified as sources of contamination by *Campylobacter spp*. These circumstances require implementing practices and design manuals for appropriate hygienic handling to reduce or eliminate contamination risks as meat moves along the alimentary chain. The antimicrobial resistance of *Campylobacter spp*. in samples from three species: camels, cattle, and water buffaloes. The frequencies reported for this microorganism as diagnosed by PCR were water buffalo, 21.4%; beef, 9.2%; and camel, 2.3%. *Campylobacter jejuni* had the highest incidence (77.4%), followed by *Campylobacter coli* at 22.6% [63]. The resistance of contaminating microorganisms in meat to antibiotic treatment constitutes a latent risk for human populations. In the study mentioned above [63] also determined the resistance of those microorganisms to various drugs, finding that it ranged from 26-87% [63]). The most important finding was the high frequency of microbial contamination in buffalo meat, surely associated with ineffective or deficient hygiene practices, though the possibility that buffaloes are more susceptible to contagion cannot be discarded. These issues can only be resolved by carrying out additional studies focused on innocuity. Under these conditions of contamination/food safety, several efficient methods of conservation have been applied, such as irradiating carcasses with gamma rays and treating, reducing, or eliminating pathogenic microorganisms; unfortunately, no studies of buffalo carcasses have yet adopted this line of investigation.

In European countries, buffalo meat is considered an alternative product, contained high nutritional value and innocuity. Studies of buffalo meat there have focused on conserving the commercial quality of products and determining the best practices for culinary preparation. In evaluating the effects of three cooking methods (boiling, grilling, frying) on the lipid chemical composition, all three methods reduced moisture and increased the protein, ash, and fat content [64]. The increase in fat content was greatest when the meat was fried in olive oil, but that meat was lower in saturated fats due to the oil's content, which contributed monounsaturated fatty acids (C18:1). Incorporating oil caused a decrease in the content of conjugated linoleic acid. The fried meat also had the highest levels of trans fatty acids, which are considered unhealthy for humans. They concluded that frying was the worst method for cooking buffalo meat. Both boiling and grilling increased the reactive substances to thiobarbituric acid, but frying had no effect on these compounds.

With respect to buffalo meat's shelf life, at the time of writing, we were unable to locate any scientific research dealing with this issue or the different types of packaging used in commercializing this product. This leads us to suggest an urgent need to develop intelligent packaging studies designed to prolong shelf life through evaluations of the generation of biogenic amines in buffalo meat. To control the deterioration of the compounds characteristic of this meat, studies have been undertaken to prevent lipid oxidation by applying carnosic acid extracted from the dry leaves of rosemary plants. Research has shown that carnosic acid has an inhibitory effect on lipid oxidation in both raw and prepared buffalo meat –and chicken– leading Naveena *et al*. [65] to conclude that a dose of 22.5 ppm of carnosic acid is effective in inhibiting the lipid oxidation that modifies the color of refrigerated buffalo meat.

DEMAND AND THE MARKET

The principle buffalo meat-producing countries are India 49%, Pakistan 25%, China 10%, and Nepal [66]. On the American continent, Brazil, Venezuela, Colombia, Costa Rica, Cuba, and Mexico have shown a growing interest in raising buffaloes over the past 15 years. Producers attribute the increase in the breeding of buffaloes to this species' ability to adapt to edaphoclimatic conditions that are adverse for cattle and other ruminants. However, suppose the goal is to produce meat of the quality required to compete with that of other species. In that case, these buffaloes need to receive high-quality forage and cereals that satisfy their nutritional requirements and allow them to achieve maximum genetic vigor in terms of weight gain. Unfortunately, there are only limited studies of the economic feasibility of producing buffalo meat and very little consolidated livestock infrastructure worldwide, which is necessary if we are to develop systematic market studies of buffalo milk and meat [4, 5]. One example of integration in the productive chain and the economic feasibility of buffalo meat production can be found in the Philippines' research, which focused initially on implementing the flow chart proposed in Figure **2**.

The meat-value chain consists of 7 participative steps: a) input suppliers; b) ranchers; c) technical and

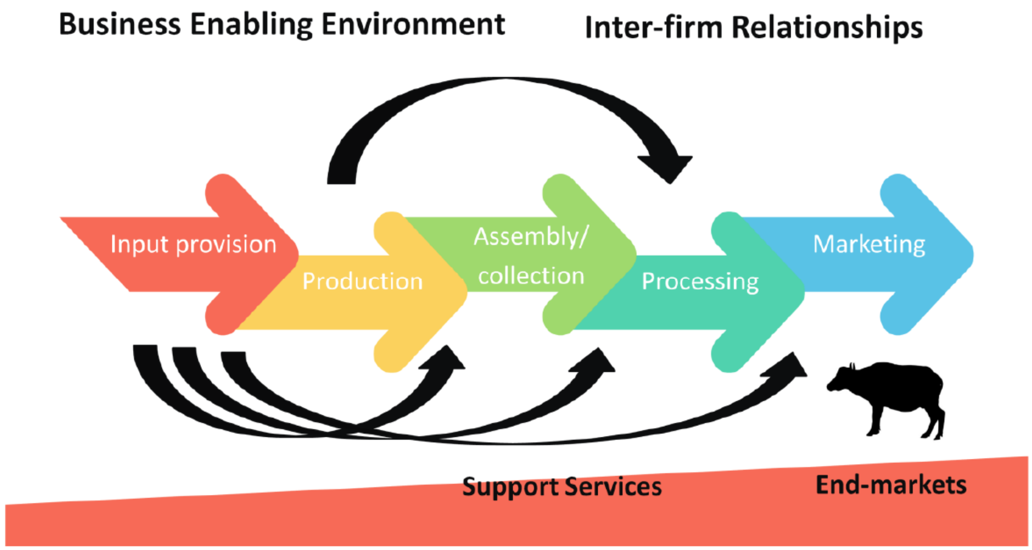

Figure 2: The value chain of river buffalo meat.

administrative agents; d) commercializers; e) wholesale and retail meat distributors; f) wholesale meat processors, and g) retail meat processors (Figure **2**).

The results of cost/yield analyses conducted on farms in The Philippines indicate positive net incomes for ranchers due, primarily, to the sale of buffaloes. The largest outlays were for alimentation and labor. However, the highest financial gain per kg of fresh buffalo meat was 60% for the retail merchants. In comparison, profits to ranchers averaged only 15%. In the case of meat processed by companies in The Philippines, profits reached 50-60%, while retailers only achieved a return of 30% [66]. The direct producers have lower profits, limited by factors related to the costs of forage and concentrates, problems with water supplies, low levels of technologies in feedlots, deficient genetic improvement, issues involving fertility, scant financial support, scarce participation by consultants/experts, irregularities in supplying retailers with meat, poor implementation of packaging and labeling technologies, and deficient commercial promotion of buffalo meat [66]. Once again, we found a dearth of studies carried out with the aim of identifying factors that could increase the acceptance and consumption of buffalo meat, such as increasing government or private sector support –or both– for primary production in view of the growing demand for buffalo meat in high-consumption countries [5].

Another factor that limits the acquisition of buffalo meat is the market price. In Europe and Latin America, the price of buffalo meat commercialized in focalized places where tourism or a nucleus of middle-to-upper class society can purchase it is generally around 5-20% higher than the cost of beef. In this regard, the feasibility study of free-roaming buffalo production in Latin America [67] that applied a methodology based on capital budgets, nominal cash flows, indicators of financial profitability with internal return rates, net real valor, cost/benefit analysis, and the period for recovering investment, concluded that the system of buffalo production evaluated was not profitable for ranchers. Research initiatives like this one suggest the need to implement programs of genetic improvement and to broaden market possibilities for buffalo milk and meat in order to stimulate demand for buffalo products and so increase returns on investment.

AUTHENTICITY: MOLECULAR TECHNIQUES IN MEAT

In Asian countries today, the consumption of buffalo meat is high, and products are exported to Europe. However, as consumption of this product increases, it becomes susceptible to adulteration, just like any other commodity that has high economic value. Adulteration can involve replacing, adding, or supplanting labels. For example, in India, water buffalo meat (*Bubalus bubalis*) is often adulterated with sheep meat because of its lower cost and wide availability. At the same time, the meat of *Bos indicus* cattle is sometimes adulterated with buffalo meat as a way to obtain higher prices for export products [68]. In some countries of the American continent, in contrast, the problem is just the opposite, for buffalo meat is commercialized at a higher price than beef, justified by its beneficial nutritional quality for human health and because it is considered exotic meat, like that of wild species of animals and birds that are hunted. Due to these circumstances, several studies have been conducted to test the implementation of molecular techniques to identify adulteration in both beef and river buffalo meat.

Buffalo meat from Asia is of only fair-to-good quality because the animals are not genetically selected, so their characteristics depend more on the production system and the types of animals sent to slaughter (often cachectic or old buffaloes). This is precisely the kind of meat used to adulterate fresh or processed beef [38].

Due to these fraudulent operations, modern techniques like proteomics have been employed. They utilize specific peptidic biomarkers that have the capacity to provide information on animal species and the various elements that may appear in mixtures of different meats [69]. Several studies report detecting quantities below 1% of meat used as an adulterant by means of separating proteins in liquid form. These methodologies use isoelectric pH values as a determining factor of protein content using OFFGEL electrophoresis and identifying the proteins by liquid chromatography-tandem mass spectrometry (LC-MS/MS) [70]. This method requires specific peptides of species derived from the light chains of myosin 1 and myosin 2 to detect the presence of buffalo meat. The proteomic technique, coupled with OFFGEL electrophoresis, is further associated with methods based on DNA detection. The -polymerase chain reaction (PCR) technique has been developed using the techniques of random amplification of polymorphic DNA [71], PCR restriction fragment length polymorphism [72], and a specific primer for buffalo with the following structure: Forward: 5′CTG CAA CCA TCA ACA CAC CTA AC 3′; Reverse: 5′CGG CCA TAG CTG AGT CCA AG 3′, based on the mitochondrial gene of the DNA-D loop to amplify the DNA in samples from various breeds of buffalo, including Murrah, Toda, Panderpuri, Badawari, Surati, and Nili-Ravi [68]. Clearly, great strides have been made in determining the buffalo's genome. In the future, this may provide an additional diagnostic tool for determining the quality and authenticity of meat from young buffaloes raised to reach their maximum development in a short period of time.

CONCLUSIONS

The market for river buffalo meat presents both producers and researchers with a genuine challenge that can only be addressed adequately through a multi- and interdisciplinary approach that assesses in detail every step of the production chain.

What follows is a list of the principal aspects requiring more studies.

a. Identifying the best production system in terms of profitability while also achieving optimal levels of productive performance and competitive characteristics in buffalo carcasses.

b. Generating diets that satisfy the specific nutritional requirements of buffaloes and foster excellent protein-fat ratios in meat while also ensuring the instrumental characteristics that determine meat quality.

c. Suggesting conservation and packaging methods appropriate for buffalo meat during commercialization.

d. Implementing novel methodologies for detecting the adulteration of buffalo meat.

REFERENCES

[1] Tamburrano A, Tavazzi B, Maria Callà CA, Amorini AM, Lazzarino G, Vincenti S, *et al*. Biochemical and nutritional characteristics of buffalo meat and potential implications on human health for a personalized nutrition. Ital J Food Saf 2019; 8: 174-179. https://doi.org/10.4081/ijfs.2019.8317

[2] FAO. 2015. Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, World Food Programme. The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: Taking Stock of Uneven Progress. FAO.

[3] FAO. 2019. Sustainable Development Goals (SDG). End hunger, achieve food security and improved nutrition and promote sustainable agriculture. http://www.fao.org/sustainable-development-goals/news/detail-news/en/c/424259/

[4] Bertoni A, Álvarez-Macias A, Mota-Rojas D. Productive performance of buffaloes and their development options in tropical regions. Soc Rur Prod Med Amb 2019; 19: 59-80.

[5] Bertoni A, Napolitano F, Mota-Rojas D, Sabia E, Alvarez-Macias A, Mora-Medina P, *et al*. Similarities and differences between river buffaloes and cattle: health, physiological, behavioural and productivity aspects. J Buffalo Sci 2020; 9: 92-109. https://doi.org/10.6000/1927-520X.2019.08.03.12

[6] Guerrero-Legarreta I, Napolitano F, Mota-Rojas D, Cruz-Monterrosa R, Mora-Medina P, Berdugo-Gutiérrez J. El búfalo de agua, versatil y rústico como productor de carne. Agro Meat. Buenos Aires, Argentina 2019; Febrero: 1-10.

[7] Guerrero-Legarreta I, Napolitano F, Cruz-Monterrosa RG, Mota-Rojas D, Mora-Medina P, Ramírez-Bribiesca E, *et al*. A River buffalo meat production and quality: sustainability, productivity, chemical composition and sensory properties. J Buffalo Sci 2020; 9: 159-169. https://doi.org/10.6000/1927-520X.2020.09.17

[8] Neath KE, Del Barrio AN, Lapitan RM, Herrera JR, Fujihara T, Muroya S, *et al*. Protease activity higher in postmortem

water buffalo meat than Brahman beef. Meat Sci 2007; 77: 389-96.
https://doi.org/10.1016/j.meatsci.2007.04.010

[9] Robertson J, Bouton PE, Harris PV, Shorthose WR, Ratcliff D. A comparison of some properties of beef and buffalo (*Bubalus bubalis*) meat. J Food Sci 1983; 48: 686-690.
https://doi.org/10.1111/j.1365-2621.1983.tb14876.x

[10] Sharma N, Gandemer G, Goutefongea R, Kowale BN. Fatty acid composition of water buffalo meat. Meat Sci 1986; 16: 237-243.
https://doi.org/10.1016/0309-1740(86)90029-X

[11] Naveena BM, Mendiratta SK, Anjaneyulu ASR. Tenderization of buffalo meat using plant protease from *Cucumis trigonus ruxb* (Kachri) and *Zingiber officinale roscoe* (*Ginger rhizome*). Meat Sci 2004; 68: 363-369.
https://doi.org/10.1016/j.meatsci.2004.04.004

[12] Naveena BM, Kiran M, Sudhakar Reddy K, Ramkrishna C, Vaithiyanathan S, Devatkal SK. Effect of ammonium hydroxide on ultrastructure and tenderness of buffalo meat. Meat Sci 2011; 88: 727-732.
https://doi.org/10.1016/j.meatsci.2011.03.005

[13] Kandeepan G, Biswas S, Rajkumar RS. Buffalo as a potential food animal. Int J Livest Prod 2009; 1: 001-005.

[14] Neath KE, Del Barrio AN, Lapitan RM, Herrera JRV, Fujihara T, Muroya S, *et al*., Difference in tenderness and pH decline between water buffalo meat and beef during postmortem aging. Meat Sci 2007; 75: 499-505.
https://doi.org/10.1016/j.meatsci.2006.08.016

[15] Kiran M, Naveena BM, Reddy KS, Shahikumar M, Reddy VR, Kulkarni V, *et al*. Muscle-specific variation in buffalo (*Bubalus bubalis*) meat texture: biochemical, ultrastructural and proteome characterization. J Texture Studies 2015; 46: 254-261.
https://doi.org/10.1111/jtxs.12123

[16] FAO. 2020. Livestock systems. http://www.fao.org/livestock-systems/global distributions/buffaloes/en/

[17] Iqbal A, Mirza MA, Raza SH. Role of Buffaloe in contributing milk and meat in Pakistan. Ital J Anim Sci 2007; 6: 1387-1389.
https://doi.org/10.4081/ijas.2007.s2.1387

[18] Fundora O, Roque R, Sánchez R. Datos preliminares de la conducta alimentaria de búfalos de río en pastoreo. Cuban J Agr Sci 2001; 35: 15-17.

[19] Romero SD, Pérez de León AA. Bubalinocultura en México: retos de industria pecuaria naciente. Logros y Desafíos de la Ganadería Doble Propósito 2014; 6: 15.

[20] Marai IFM, Haeeb AAM. Buffalo's biological functions as affected by heat stress — A review. Livest Sci 2009; 127: 89-94.
https://doi.org/10.1016/j.livsci.2009.08.001

[21] Mota-Rojas D, De Rosa G, Mora-Medina P, Braghieri A, Guerrero-Legarreta I. Napolitano F. Invited review: Dairy buffalo behaviour and welfare from calving to milking. CAB Rev 2019; 14: 1-12.
https://doi.org/10.1079/PAVSNNR201914035

[22] Mota-Rojas D, Napolitano F, Bertoni MA, Gómez-Prado J, Mora-Medina P, Cruz-Monterrosa R, *et al*. Thermal biology in river buffalo in the humid tropics: neurophysiological and behavioral responses. Int J Vet Sci Med 2020; 8: (In review).

[23] Mota-Rojas D, Broom DM, Orihuela A, Velarde A, Napolitano N, Alonso-Spilsbury M. Effects of human-animal relationship on animal productivity and welfare. J Anim Behav Biometeorol 2020; 8: 196-205.
https://doi.org/10.31893/jabb.20026

[24] Bertoni A, Mota-Rojas D, Álvarez-Macias A, Mora-Medina P, Guerrero-Legarreta I, Morales-Canela A, *et al*. Scientific findings related to changes in vascular microcirculation using infrared thermography in the river buffalo. J Anim Behav Biometeorol 2020; 8: (Accepted).

[25] Maharana BR, Kumar B, Prasad A, Patbandhan TK, Sudhakar NR, Joseph JP, *et al*. Prevalence and assessment of risk factors for haemoprotozoan infections in cattle and buffaloes of South-West Gujarat, India. Indian J Anim Res 2016; 50: 733-739.
https://doi.org/10.18805/ijar.10268

[26] Benitez D, Cetrá B, Florin-Christensen M. Rhipicephalus (Boophilus) microplus ticks can complete their life cycle on the water buffalo (*Bubalus bubalis*). J Buffalo Sci 2012; 1: 193-7.
https://doi.org/10.6000/1927-520X.2012.01.02.11

[27] Desta, T. Introduction of domestic buffalo (*Bubalus bubalis*) into Ethiopia would be feasible. Renew. Agr Food Syst 2012; 27: 305-313.
https://doi.org/10.1017/S1742170511000366

[28] Paul SS, Das KS. Prediction of body weight from linear body measurements in Nili-Ravi buffalo calves. J Buffalo Sci 2012; 1: 32-4.
https://doi.org/10.6000/1927-520X.2012.01.01.06

[29] Sarkar S, Hossain M, Amin M. Socio-economic status of buffalo farmers and the management practices of buffaloes in selected areas of Bagerhat District of Bangladesh. Bangladesh J Anim Sci 2013; 42: 158-164.
https://doi.org/10.3329/bjas.v42i2.18505

[30] Mota-Rojas D, Olmos-Hernández A, Verduzco-Mendoza A, Lecona-Butrón H, Martínez-Burnes J, Mora-Medina P, *et al*. Infrared thermal imaging associated with pain in laboratory animals. Experimental Animals 2020; 69: (Accepted).

[31] Luigi Z. Influence of Seasonality on Buffalo Production. The Buffalo (*Bubalus bubalis*) Production and Research 2016; Chapter 8. pp. 196-224.
https://doi.org/10.2174/9781681084176117010011

[32] Mora-Medina P, Napolitano F, Mota-Rojas D, Berdugo J, Ruiz-Buitrago J, Guerrero-Legarreta I. Imprinting, Sucking and allosucking behaviors in buffalo calves. J Buffalo Sci 2018; 7: 49-57.
https://doi.org/10.6000/1927-520X.2018.07.03.3

[33] Mora-Medina P, Berdugo-Gutiérrez J, Mota-Rojas D, Ruiz-Buitrago J, Nava AJ, Guerrero-Legarreta I. Behaviour and welfare of dairy buffaloes: pasture or confinement?. J Buffalo Sci 2018; 7: 43-48.
https://doi.org/10.6000/1927-520X.2018.07.03.2

[34] McCool C. Buffalo and Bali cattle—Exploiting their reproductive behaviour and physiology. Trop. Anim. Health Prod 1992; 24: 165-172.
https://doi.org/10.1007/BF02359609

[35] Muñoz-Berrocal M, Tonhati H, Cerón-Muñoz M, Duarte JMC, Chabariberi RL. Uso de modelos lineares e não lineares para o estudo da curva de lactação em Búfalos Murrah e seus mestiços em sistema de criação semi extensivo, no Estado de São Paulo. Arch Latinoam Prod Anim 2005; 13: 19-23

[36] Angulo RA, Noguera RR, Berdugo JA. El búfalo de agua (*Bubalus bubalis*) un eficiente utilizador de nutrientes: aspectos sobre fermentación y digestión ruminal. Livest Res Rural Dev 2005; 17: 67-71.

[37] Tauqir NA, Shahzad MA, Nisa M, Sarwar M, Fayyaz M, Tipu MA. Response of growing buffalo calves to various energy and protein concentrations. Livest Sci 2011; 137: 66-72.
https://doi.org/10.1016/j.livsci.2010.10.003

[38] Hamid MA, Zaman MA, Rahman A, Hossain KM. Buffalo Genetic Resources and their Conservation in Bangladesh. Res J Vet Sci 2017; 10: 1-13.
https://doi.org/10.3923/rjvs.2017.1.13

[39] Naveena BM, Kiran M. Buffalo meat quality, composition, and processing characteristics: contribution to the global economy and nutritional security. Anim Frontiers 2014; 18-24.
https://doi.org/10.2527/af.2014-0029

[40] NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th ed. National Academies Press, Washington, DC 2001.

[41] NRC. 2016. Nutrient Requirements of Beef Cattle 8th ed. National Academies Press, Washington, DC 2016.

[42] Paul SS, Lal D. Nutrient requirements of buffaloes Azadpur-Dellhi: Satish Serial Publishing House 2010; 137.

[43] Mendes AJ, Lima F. Aspectos nutricionales del búfalo. Tecnología en Marcha, SeDAFP y Universidad Popular de la Chontalpa 2011; 516: 105-120.

[44] Kala A, Kamra DN, Kumar A, Agarwal N, Chaudhary LC, Joshi CG. Impact of levels of total digestible nutrients on microbiome, enzyme profile and degradation of feeds in buffalo rumen. PLoS ONE 2017; 12: e0172051. https://doi.org/10.1371/journal.pone.0172051

[45] Giordano G, Guarini P, Ferrari P, Biondi-Zoccai G, Schiavone B, Giordano A. Beneficial impact on cardiovascular risk profile of water buffalo meat consumption. Eu J Clin Nutr 2010: 64: 1000-1006. https://doi.org/10.1038/ejcn.2010.108

[46] Ordovas JM, Ferguson LR, Tai ES, Mathers JC. Personalised nutrition and health. BMJ 2018; 361: k2173. https://doi.org/10.1136/bmj.k2173

[47] USDA, 2015. National Nutrient Database for Standard Reference, Release 28.

[48] Landi N, di Giuseppe AMA, Ragucci S, di Maro A, Free amino acid profile of *Bubalus bubalis* L. meat from the Campania region. Rev Brasil Zootec 2016; 45: 627-31. https://doi.org/10.1590/S1806-92902016001000008

[49] Soria LA, Corva PM. Factores genéticos y ambientales que determinan la terneza de la carne bovina. Arch. Latinoam Prod Anim 2004; 12: 73-88

[50] Giuffrida-Mendoza M, Arenas de Moreno L, Huerta-Leidenz N, Uzcategui-Bracho S, Valero-Leal K, Romero S, *et al*. Cholesterol and fatty acid composition of longissimus thoracis from water buffalo (*Bubalus bubalis*) and Brahman-influenced cattle raised under savannah conditions. Meat Sci 2015; 106: 44-49. https://doi.org/10.1016/j.meatsci.2015.03.024

[51] Giuffrida-Mendoza M, Arenas-Moreno L, Huerta-Leidenz N, Uzcátegui-Bracho S, Hamid MA, Siddiky MNA, Rahman MA, Hossain KM. Scopes and opportunities of buffalo farming in Bangladesh a review. SAARC J Agri 2016; 14: 63-77. https://doi.org/10.3329/sja.v14i2.31246

[52] Kandeepan G, Mendiratta SK, Shukla V, Vishnura MR. Processing characteristics of buffalo meat- a review. J Meat Sci Technol 2013; 1: 1-9.

[53] Di Luccia A, Satriani A, Barone CMA, Colatruglio P, Gigli S, Occidente M, *et al*. Effect of dietary energy content on the intramuscular fat depots and triglyceride composition of river buffalo meat. Meat Sci 2003; 65: 1379-1389. https://doi.org/10.1016/S0309-1740(03)00060-3

[54] Faustman C, Yin S, Tatiyaborworntham N, Naveena BM. Oxidation and protection of red meat. Part1. In: E. Decker, R. Elias, and D.J. McClements, editors, Oxidation in foods and beverages and antioxidant applications: Management in different industry sectors. Volume 2. Woodhead Publishers, Cambridge, UK 2010; pp. 3-49. https://doi.org/10.1533/9780857090331.1.3

[55] Bosques J, Pagán-Morales M, Casas A, Rivera A, Cianzio D. Segregation of polymorphisms in µ-calpain and calpastatin in beef cattle in Puerto Rico. J Agr U Puerto Rico 2015; 99: 105-116.

[56] Nuraini H, Mahmudah A, Winarto A, Sumantri C. Histomorphology and Physical Characteristics of Buffalo Meat at Different Sex and Age. Media Peternakan 2013; 4: 6-13. https://doi.org/10.5398/medpet.2013.36.1.6

[57] Aminzare M, Hashemi M, Hassanzad Azar H, Hejazi J. The Use of Herbal Extracts and Essential Oils as a Potential Antimicrobial in Meat and Meat Products: A Review. J Hum Environ Health Promot 2016; 1: 63-74. https://doi.org/10.29252/jhehp.1.2.63

[58] Nampanya S, Young J, Khounsy S, Bush R, Windsor P. Open access the food security challenge for the buffalo meat industry: perspectives from Lao PDR. J Buffalo Sci 2014; 3: 38-47. https://doi.org/10.6000/1927-520X.2014.03.02.2

[59] Hernández-Macedo, M. L., Barancelli, G. V., Contreras-Castillo, C. J. Microbial deterioration of vacuum-packaged chilled beef cuts and techniques for microbiota detection and characterization: a review. Braz J Microbiol 2011; 42: 1-11. https://doi.org/10.1590/S1517-83822011000100001

[60] Manzoor A, HayatJaspal M, Yaqub T, UlHaq A, Nasir J, Avais M, *et al*. Effect of lactic acid spray on microbial and quality parameters of buffalo meat. Meat Sci 2020; 159: 107923. https://doi.org/10.1016/j.meatsci.2019.107923

[61] Biswas AK, Kondaiah N, Bheilegaonkar KN, Anjaneyulu AS, Mendiratta SK, Jana C. Microbial profiles of frozen trimmings and silver sides prepared at Indian buffalo meat packing plants. Meat Sci 2008; 80: 418e422. https://doi.org/10.1016/j.meatsci.2008.01.004

[62] Voloski FLS, Tonello L, Ramires T, Reta GG, Dewes C, Iglesias M, *et al*. Influence of cutting and deboning operations on the microbiological quality and shelf life of buffalo meat. Meat Sci 2016; 116: 207-212. https://doi.org/10.1016/j.meatsci.2016.02.020

[63] Rahimi E, Ameri M, Alimoradi M, Chakeri A, Bahrami AR. Prevalence and antimicrobial resistance of Campylobacter jejuni and Campylobacter coli isolated from raw camel, beef, and water buffalo meat in Iran. Com Clin Path 2013; 22: 467-473. https://doi.org/10.1007/s00580-012-1434-5

[64] Juárez M, Failla S, Ficco A, Pen F, Avilés C, Polvillo O. Buffalo meat composition as affected by different cooking methods. Food Bioprod Proce 2010; 88: 145-148. https://doi.org/10.1016/j.fbp.2009.05.001

[65] Naveena BM, Vaithiyanathan S, Muthukumar M, Sen AR, Praveen-Kumar Y, Kiran M, *et al*., Relationship between the solubility, dosage and antioxidant capacity of carnosic acid in raw and cooked ground buffalo meat patties and chicken patties. Meat Sci 2013; 95: 195-202. https://doi.org/10.1016/j.meatsci.2013.04.043

[66] Lantican FA, Molina MC, Lapitan JE, Padrid JC, Suñaz EC, Cañizares AR, *et al*. Buffalo Meat Value Chain Analysis in Luzon, Philippines. Department of Agriculture. Philippine Carabao Center. Searca 2017; p. 121.

[67] Díaz-Gutiérrez C, WingChing-Jones R, Rosales-Rodríguez R. Factibilidad del establecimiento de un sistema de producción de engorde de búfalos en pastoreo. Agronomía Costarricense 2009; 33: 183-191.

[68] Mane BG, Mendiratta SK, Tiwari AK, Bhilegaokar KN. Detection of adulteration of meat and meat products with buffalo meat employing polymerase chain reaction assay. Food Anal Methods 2012; 5: 296-300. https://doi.org/10.1007/s12161-011-9237-x

[69] Kiran M, Naveena BM, Reddy KS, Shahikumar M, Reddy VR, Kulkarni V, Rapole S, More TH. Understanding tenderness variability and ageing changes in buffalo meat: biochemical, ultrastructural and proteome characterization. Animal 2016; 10: 1007-1015. https://doi.org/10.1017/S1751731115002931

[70] Sentandreu M Á, Sentandreu E. Authenticity of meat products I: tools against fraud. Food Res Inter 2014; 60: 19-29. https://doi.org/10.1016/j.foodres.2014.03.030

[71] Wang L, Hang X, Geng R. Molecular detection of adulteration in commercial buffalo meat products by multiplex PCR assay. Food Sci Technol 2019; 39: 344-348. https://doi.org/10.1590/fst.28717

[72] Girish PS, Haunshi S, Vaithiyanathan S, Rajitha R, Ramakrishna C. A rapid method for authentication of Buffalo (*Bubalus bubalis*) meat by Alkaline Lysis method of DNA extraction and species specific polymerase chain reaction. J Food Sci Technol 2013; 50: 141-146. https://doi.org/10.1007/s13197-011-0230-6

Received on 24-06-2020 Accepted on 14-07-2020 Published on 13-08-2020

DOI: https://doi.org/10.6000/1927-520X.2020.09.18