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A Systematic Review on Buffalo Breeds, Lactation Performance, and Buffalo Milk Production Characteristics in Sri Lanka

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ABSTRACT

Purpose: *The current study aimed to systematically review the publications originating from Sri Lanka on buffalo milk to identify potential dairy buffalo breeds and their lactation performances, milk composition, physicochemical properties, and products originating from buffalo milk.*

Research Method: *Articles published over the last 6 decades were found through Scopus and Google Scholar databases using keywords. Original Research articles which are relevant and published in English were only selected. The six-step selection process in line with the Preferred Reporting Items for Systematic Reviews and Meta-analysis Approach (PRISMA) was adopted.*

Findings: *The majority of the publications focused on product development aspects rather than buffalo milk production aspects. Pure breeds of the locals, Murrah, Surti, and Nili-Ravi, and their crossbreeds are frequently cited in the literature. The daily average milk yields of Murrah, Local, Surti, and Nili-Ravi pure breeds were 4.7±2.3, 3.1±1.3, 3.0±1.19, and 1.2 L, respectively. Daily milk yields of the crossbreeds ranged from 1.1 – 5.0 L. Average lactation lengths were largely dependent on the breed in which Murrah recorded the highest (341±100 days). The average lactation length of the local breed was exceptionally shorter (156±27 days) than that of the exotic breeds (>235 days). The calving interval of the Murrah and Local buffaloes was the same (636 d). Pure breeds of Surti and Nili-Ravi recorded calving intervals of 489 and 411 d, respectively. Whereas, it ranged from 417-477 d among crossbreeds. Studies focused on milk compositions and physicochemical properties were extremely rare. Curd and cheese were the most focused products originating from buffalo milk.*

Value: *This study summarises the buffalo milk production aspects in Sri Lanka and identifies research gaps in the area. Current literature reflects a satisfactory level of information relevant to the buffaloes reared in the Dry-Zone. This study recommends more research in milk composition analysis and lactation performance of the breeds and buffalo production in the Low-Country Wet Zone and Up-Country regions.*

Keywords: *Bubalus bubalis, Buffalo milk products, Curd, Lactation performance, Lanka buffalo*

INTRODUCTION

Buffaloes are one of the major milk-producing animals distributed predominantly in the tropical and subtropical areas in Asia. Buffalo milk accounts for approximately 15% of the total milk production in the world and has recorded an increasing trend in production over the years (FAOSTAT, 2022). Compared to cow milk, buffalo milk contains higher contents of protein, butter fat, vitamins, and minerals (Mahanama, 2008; Abesinghe *et al.*, 2020). Due to the higher total solid content in buffalo milk, it is advantageous in the preparation of milk products produced by curdling, such as cheese, curd, and yogurt, as the yield of these products is higher when prepared from buffalo milk compared to cow milk.

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Buffalo breeds can be divided into two broader categories: swamp buffaloes and river buffaloes. Out of these two, river buffaloes (e.g., Murrah, Nili-Ravi, and Surti) are extensively been utilized as milking animals. Buffaloes are also utilized as multipurpose animals to obtain dung and hides and as a source of animal draught power for agriculture.

Being a tropical country located in the South Asian region, the buffalo plays a vital role in the livestock sector and as an integral part of the rural farming systems in Sri Lanka. Presently, most of the buffaloes in Sri Lanka are reared as dairy animals.Buffalo milk contributes about 16% of the total milk production in Sri Lanka and the production level is being increased over the years (DAPH, 2019). Buffalo milk production in Sri Lanka varies according to breed, management practices, and environmental conditions. The lack of recent research on buffalo milk production is identified as one of the main limitations to uplifting the buffalo industry in Sri Lanka. Although there are some research available on milk yields, breeds, and milk production characteristics of buffaloes reared in different agro-climatic zones in Sri Lanka, a comprehensive review of the published research is absent to the best of our knowledge.

Based on this context, the objective of this systematic review was to understand existing knowledge on buffalo milk production characteristics in Sri Lanka based on the research published within the last 6 decades (from 1960 to 2021). It aimed to identify potential dairy breeds and lactation performance of buffalos, milk composition and physicochemical properties of buffalo milk, and production of buffalo milk products and their improvements.

MATERIALS AND METHODS

A comprehensive and systematic literature survey was conducted on the topic-specific keywords as listed in Table 1 to find research articles published in English over the last 60 years (between 1960 to 2021). The literature survey was conducted using the academic databases, Scopus and Google Scholar.

Only the original research articles were included in the review, excluding all review papers, summary papers, books, and articles with contents not relevant to the current systematic review.The primary search terms “Buffalo”, “Sri Lanka” and “milk” were combined using the Boolean search term; AND to search the literature. Additional search terms “lactation”, “milk composition”, “milk yield” and “agro-climatic zones” were used to make it more specific and limit the literature searches further.

The six-step selection process in line with the Preferred Reporting Items for Systematic Reviews and Meta-analysis Approach (PRISMA) was adapted as previously published by Brennan *et al.* (2021). Titles and abstracts of search results were screened for relevance and duplicates were removed. Selected articles were screened, and further exclusions were made where necessary. Articles published with predatory publishers were also omitted. For this purpose, Baell’s List of Potential Predatory Journals and Publishers was used (Beallslist, 2017). Full-text articles assessed for eligibility were entered into a spreadsheet mentioning the important data, namely the objective of the research, study area, management system, breed, composition of buffalo milk, milk production characteristics, milk yield, buffalo milk products mentioned, characteristics of them, results and conclusions of the articles. Accordingly, forty-two (42) articles were selected for the qualitative analysis (Fig. 01).

RESULTS AND DISCUSSION

Analysis of Bibliographic Information

The forty-two (42) academic publications considered in this review consisted of 16 journal articles, 16 conference proceedings, 5 Doctoral dissertations, 4 technical/research reports, and 1 pre-print. Among these, just over 80% of the articles were published from 2008 onward and about 67% were published from 2013-2021 suggesting a continued and growing interest in the field (Fig. 02).

A total of 96 authors have contributed to the 42 academic publications selected for the current review. However, only 45 authors contributed to journal papers. Tables 2 and 3 provide an overview of the papers published by the journals and the top authors who contributed to the academic publications. These authors were able to publish their articles in 15 different journals (7 with foreign publishers and 8 with local publishers). Results suggest that more than 50% of the articles considered in the study were published in preliminary forms including the abstracts in conference proceedings, technical/research reports, Doctoral dissertations, and pre-prints. Out of the 96 authors, only 14 authors (~15% of the total) have more than one publication.

The research focus of the academic publications selected for the review is summarized in Table 4. The

Table 1: Keywords used in database search

Query number	First level term	Second level term	Third level term	Fourth level term	Fifth level term	No. of articles
1	Buffalo	Sri Lanka	Milk			7621
2	Buffalo	Sri Lanka	Milk	Lactation	Milk composition	217
3	Buffalo	Sri Lanka	Milk	Milk yield	Agro-climati zones	43
					Total papers	7881

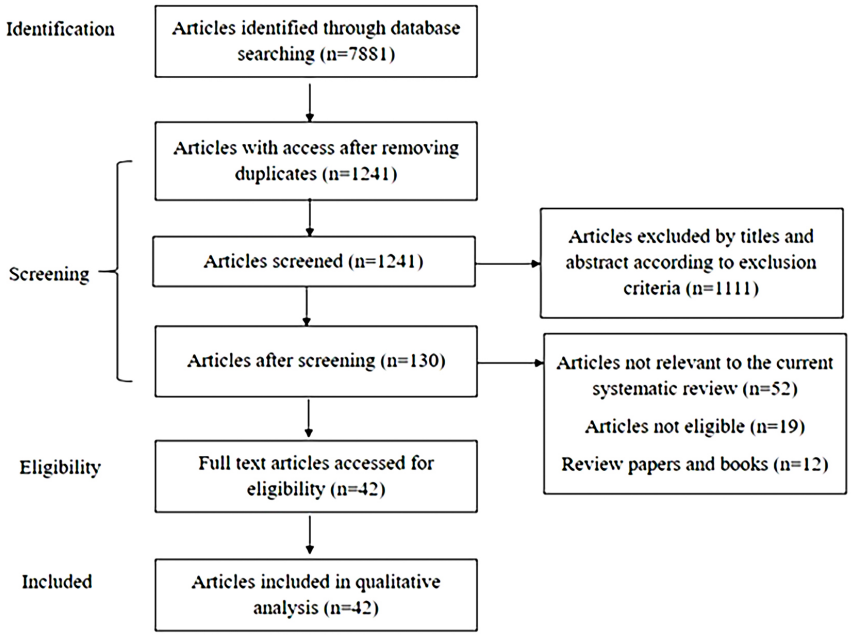

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analysis Approach (PRISMA) flow diagram

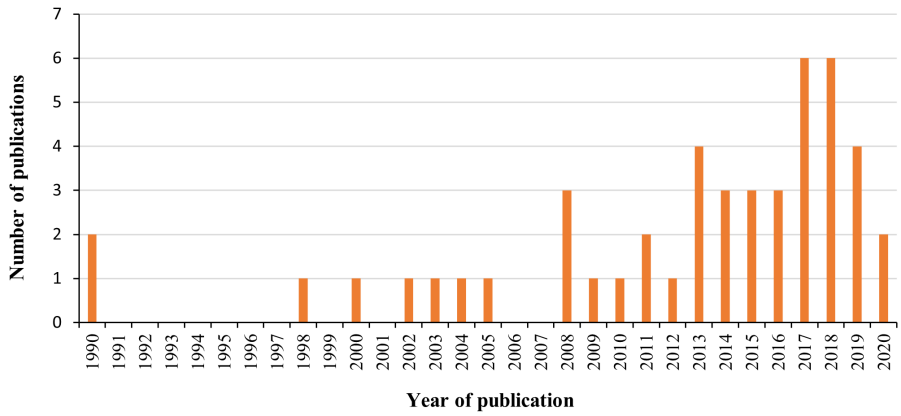

Figure 2: Academic publications on buffalo milk originated in Sri Lanka during the period 1960-2020

majority of the publications (25 out of 42) focused on aspects related to buffalo milk processing such as product development, product quality, characteristics and improvement of buffalo milk products, development of starter cultures, milk processing techniques, bioactivities, and microbiological aspects. In contrast, only 17 articles focused on buffalo milk production-related aspects. These have addressed the socioeconomic and cultural aspects of buffalo production, breed characteristics, the milking performance of different

breeds under various agro-climatic conditions, cleaner milk production, and milk composition-related aspects. Results suggest that much of the research has focused on buffalo milk processing aspects and much research needs to be dedicated to investigating buffalo milk production aspects to identify suitable dairy buffalo breeds for various agro-climatic conditions around the country and to improve their production efficiencies through better management and feeding practices.

Buffalo Breeds in Focus

Local buffalos are indigenous to Sri Lanka and available in large numbers throughout the country. From ancient times, buffaloes have been an integral part of the agricultural farming systems in the country, and have been intensively used as a multipurpose animal that provides draught power for certain agricultural practices (e.g., ploughing, threshing, etc.), as a source of manure and hides, and for milk especially to manufacturing curd. However, the milk production capacity of the Local buffalo is considerably lower than that of the specialized dairy buffalo breeds and their crosses. For this reason, pure lines of exotic dairy breeds such as Murrah and Nili-Ravi have been used for upgrading the local breed to its milk production capabilities.

Out of the 42 academic publications considered in this review, only 10 publications mentioned the breeds. Approximately 90% of those publications have focused on local breeds and Murrah. Fifty percent (50%) of the publications mentioned about Nili-Ravi and Murrah crosses. Less than 30% of the publications focused on Surti, Surti crosses, Nili-Ravi crosses, and local crosses. Various buffalo breeds reported in the publications and the agro-climatic regions where those researches were conducted are summarized in Table 5. Literature suggests that most of the studies took place in the Dry Zone and Intermediate zones and those conducted in the Low-Country Wet Zone and Upcountry were extremely rare. However, as the environmental conditions prevailing in the low-country wet zone and upcountry areas are well suited for high-potential dairy breeds, there should be more studies dedicated to identifying milk production capabilities and efficiencies of the above breeds in these areas.

Milk Yields of Buffaloes

The milk yield in buffalo shows variations with the management practices, age, health status, environmental conditions, and breed. The milk yield of the buffaloes was studied in just over 10% of the publications selected in the current review. Table 6 summarizes the milk yield of buffaloes by their breed and agro-climatic zones. The reported milk yields showed a huge variation depending on the breed and the agro-climatic region. If pure breeds are concerned, the average daily milk yields of local buffalo, Murrah, and Surthi were 3.1±1.3, 4.7±2.3, and 3.0±1.9 liters, respectively. In contrast, the average daily milk yields of the Murrah crossbreed and Surti crossbreed were 3.9±2.8 and 3.3±2.2 liters. Readings for Nili-Ravi purebreed, local crossbreed, and Nili-Ravi crossbreed were only available in a single publication each and therefore a fair calculation for the average daily milk yield is impossible. Based on the available results, it can be suggested that Murrah, Surti crossbreeds, and local crossbreeds thrive well under the local conditions in terms of average daily milk production.

Kanakkahewage (2016) reported that milk yields can be increased by feeding forages with high-quality concentrate rations and by minimizing stress in buffaloes. It has also been reported that the milk yield of the buffaloes in Sri Lanka can also be increased with a proper plan of nutritional management to provide optimum feeding, health care management, and proper shelter to prevent the effect of heat stress on buffaloes (Charlini and Sinniah, 2015; Andersson, 2019). Genetic improvement in buffaloes has also been suggested as a strategy to increase milk yields. Dematawewa and Dekkers (2014) confirmed that milk production can be improved by genetic improvement since the Surti breed was a better milk producer than the Murrah breed. The interaction between genotype and environment with poor management conditions has caused this variation in milk production. It was highlighted that there is a high potential to improve the milk yields of buffaloes in the country as the recorded average milk yields were below the genetic potential of the buffalo breeds (Ibrahim and Jayatileka, 2000).

Composition of Buffalo Milk

Buffalo milk has a desirable creamy texture compared to cow milk due to its higher proportion of fat, protein, lactose, and minerals (Priyadharshanie, 2003). Out of the publications selected for the current review, only the study of Horadagoda (1990) reported the composition of buffalo milk and colostrum (Table 7). These compositions are of the milk of the local buffalo breed and the studies related to the milk compositions of the other buffalo breeds in Sri Lanka are not available to the best of our knowledge.

Table 2: List of Journals and Number of Publications

Journal	Publisher	Number of Publications
Asian-Australasian Journal of Animal Sciences	Asian-Australasian Association of Animal Production Societies (AAAP)	2
Asian Journal of Microbiology, Biotechnology and Environmental Sciences	EM International, India	1
Ceylon Medical Journal	Sri Lanka Medical Association	1
Innovative Food Science & Emerging Technologies	Elsevier Ltd.	1
International Journal of Food Science & Technology	Institute of Food Science & Technology	1
International Journal of Multidisciplinary Studies	University of Sri Jayawardenepura, Sri Lanka	1
International Journal of Agricultural, Forestry & Plantation	WMIT Group Sdn Bhd, Malaysia	1
Journal of the National Science Foundation of Sri Lanka	National Science Foundation of Sri Lanka	1
Journal of the University of Ruhuna	University of Ruhuna, Sri Lanka	1
Livestock Research for Rural Development	Fundación CIPAV, Cali, Colombia	1
Research in Veterinary Science	Elsevier Ltd.	1
Sri Lankan Journal of Agriculture & Ecosystems	Rajarata University of Sri Lanka	1
Sri Lanka Journal of Animal Production	Sri Lanka Association of Animal Production	1
Tropical Agricultural Research and Extension	Faculty of Agriculture, University of Ruhuna, Sri Lanka	1
Wayamba Journal of Animal Science	Society of Animal Production, Wayamba University of Sri Lanka	1

Table 3: Authors having more than one publication

Rank	Author	Publication Count
1	Chandrasekara A.	3
1	Jayawardana N. W. I. A.	3
2	Gunasekara D. C. S	2
2	Ibrahim M. N. M.	2
2	Jayamanne V. S.	2
2	Jayatileka T. N.	2
2	Mangalika U. L. P.	2
2	Mudannayake D. C.	2
2	Prasanna P. H. P.	2
2	Ranadheera C. S.	2
2	Senadeera P.	2
2	Seresinghe T.	2
2	Vidanarachchi J. K.	2
2	Weerasingha W. V. V. R.	2

Table 4: The research focus of the articles

Research focus	No. of publications	Percentage (%)
Product development	12	29
Social, cultural and economic aspects of buffalo production	8	19
Characteristics of buffalo milk products	3	7
Product Quality	2	5
Health benefits of buffalo milk products	2	5
Lactation performance	2	5
Milk hygiene	2	5
Survivability of probiotic bacteria in buffalo milk products	2	5
Milk quality	1	2
Probiotic attributes of Lactic Acid Bacteria isolated from curd	1	2
Starter culture for curd manufacture	1	2
Improving product characteristics	1	2
Lactation performance and composition	1	2
Lactation performance & social, cultural & economic aspects	1	2
Milk composition	1	2
Milk protein polymorphisms among breeds	1	2
Adaptability of novel technologies for milk processing	1	2

Table 5: Buffalo breeds in Sri Lanka which have been mentioned in the research publications (from 1960-2021) considered in the current study

Breed of buffalo	Agro-climatic zone	Reference
Local buffalo	Wet zone	Horadagoda, 1990
Local buffalo, Murrah	Dry zone and Dry Intermediate zone boundary	Bandara, 1993
Local buffalo, Murrah, Nili-Ravi, Surti, Murrah×Nili-Ravi	Intermediate zone	Ibrahim and Jayatileka, 2000
Murrah, Surti	All major agro-climatic zones of the country	Dematawewa and Dekkers, 2014
Murrah, Nili-Ravi, Surti, Murrah crosses, Nili-Ravi crossed breed, Surti crossed breed	Intermediate zone	Charlini and Sinniah, 2015
Local buffalo, Murrah, Nili-Ravi	Dry zone	Hitihamu and Epasinghe, 2015
Local buffalo, Murrah, Nili-Ravi	Dry zone	Premathilaka *et al*., 2016
Murrah × non-descriptive crossed-bred	Intermediate	Kanakkahewage *et al*., 2016
Local buffalo, Murrah, Surti crossbreed, Local crossed breed	Dry zone	Ranasinghe *et al*., 2017
Local buffalo, Murrah crossbreed, Nili-Ravi crossbreed	Dry zone	Malcolm *et al*., 2019

Table 6: Milk yield of buffaloes in Sri Lanka by their breed and agro-climatic zone

Density of buffalo milk =1035 kg/m3	Local buffalo	Murrah	Nili-Ravi	Surti	Local crossbreed	Murrah crossbreed	Nili-Ravi crossbreed	Surti crossbreed	Agro-climatic zone	References
Average daily milk yield(L)	3.58								Wet zone	Horadagoda, 1990
	1.30	6.40							Intermediate zone	Ibrahim and Jayatileka, 2000
		1.20	1.15	1.16		1.07	1.06	1.17	Intermediate zone	Charlini and Sinniah, 2015
		4.10		4.90					Distributed across the country	Dematawewa and Dekkers, 2014
	4.50	7.00			5.00			5.05	Dry zone	Ranasinghe *et al*., 2017
						6.75			Intermediate zone	Kanakkahewage *et al*., 2016
Average	3.1±1.3	4.7±2.3	1.2±0.0	3.0±1.9	5.0±0.0	3.9±2.8	1.1±0.0	3.3±2.2		

Table 7: Composition of buffalo colostrum and buffalo milk reported in Sri Lanka

Component	Colostrum	Milk
Fat (g/L)	63	74.5 ± 0.6
Total protein (g/L)	150	5.16 ± 0.15
Casein (g/L)	80	44.0 ± 0.19
Lactose (g/L)	30	43.0 ± 0.02
Ash (g/L)	11	7.2 ± 0.02
Solid non-fat (g/L)	200	96.2 ± 0.46
Sodium (mg/L)		456 ± 99.6
Potassium (mg/L)		1,213 ± 356
Calcium (mg/L)		1500 ± 400
Magnesium (mg/L)		325 ± 96
Total phosphorous (mg/L)		1500 ± 400
Inorganic phosphorous (mg/L)		1,000 ± 200
Vitamin A (IU/mL)	3.3	1.20 ± 0.1
Total solids (g/L)	260	174 ± 0.57

Reference: Horadagoda (1990)

Table 8: Physicochemical parameters of the milk of the local buffalo breed in Sri Lanka (Horadagoda, 1990)

Parameter	Value
Titrable acidity	0.202 g/L
Ethanol stability	50%
Specific gravity	1.033 ± 0.003
Surface tension	46.52 ± 3.46 dynes/cm 27 °C
Viscosity	1.9633 ± 0.243 centipoises at 27 °C
Fat globule size	5.10 µm

Physicochemical Properties of Buffalo Milk

The physicochemical characteristics of buffalo milk play a key role in the processing of dairy products. Processing strategies are made based on the characteristics of milk to get the desired quality of products. Out of the selected academic publications, only one study has explored the physicochemical characteristics of buffalo milk of the local buffalo (Table 8). Studies focused on the physicochemical properties of the milk of other buffalo breeds are currently unavailable.

Lactation Performance of Buffaloes

Only about 10% of the literature selected for the current review considered exploring the lactation performance of buffalos. Lactation performances of different breeds reported in the selected literature are summarized in Table 9.

The lactation length of the buffaloes showed a greater variation among the breeds and even within the same breed in different studies. Variations in lactation length are reported to be highly correlated to the breed characteristics/genetic quality, year of calving, dry period, and season of the calving (Ibrahim and Jayatileka, 2000; Charlini and Sinniah, 2015). To maintain proper milk production on farms, the animals in the later stages of lactation are dried off or culled voluntarily or involuntarily as lower yields are observed in this stage of lactation (Dematawewa and Dekkers, 2014). It allows animals with reasonable yields to continue to be in milk. The average lactation length of the local buffalo and Murrah was 156 ± 27 and 341 ± 100 days, respectively. In contrast, lactation lengths of Surti, Nili-Ravi, and crossbreeds of Murrah, Nili-Ravi, and Surti are available in only a single reference and thus a broader comparison among different studies was not possible.

Table 9: Lactation performance of different buffalo breeds in Sri Lanka

Breed	Lactation length (in days)				Lactation number	Length of dry period (in months)	Age at first calving (in months)	Calving interval (in days)		
Indigenous	129	183						906	366	
Murrah	246		480	297	3.73	6	61.5	795		477
Surti				285	4.71	6.2	43.7			489
Nili-Ravi				237	3.5	6	44.3			411
Murrah crosses				228	2.41	5.8	44.9			417
Nili-Ravi crosses				258	2.66	7.3	46.7			474
Surti crosses				279	3.23	6.6	48.8			477
	Ibrahim and Jayatileka, 2000	Mohamed and Jeyamalar, 2005	Dematawewa and Dekkers, 2014)	Charlini and Sinniah, 2015				Ibrahim and Jayatileka, 2000	Mohamed and Jeyamalar, 2005	Charlini and Sinniah, 2015

The study of Charlini and Sinniah (2015) revealed that the lactation length of Murrah, Surti, and Surti crossbreeds goes beyond 270 days (9 months). The lowest lactation lengths were observed for Murrah crossbreed (228 days) and Nili-Ravi pure breed (237 days). However, it was 258 days for the Nili-Ravi crossbreed. Results clearly showed that the lactation lengths of exotic breeds and their crosses are remarkably higher than the local breed, and the breeds of Murrah, Surti, Surti crossbreeds, and Nili-Ravi crossbreeds thrive well in the local conditions as milking animals.

Buffaloes are known to have long calving intervals (Hallqvist, 2019). In the current literature selected for the review, the calving interval varies between 366 to 606 days (~1 year to 2½ years). The calving interval increases as the animals are preferred to milk over a longer period. It is critical to focus on the calving interval of buffaloes to maintain optimum calving intervals (Ibrahim and Jayatileka, 2000). As stated by Charlini and Sinniah (2015), age affects the increase in the performance of buffaloes with an increase in lactation by decreasing the calving interval. Two studies each mentioned the calving interval of local and Murrah buffaloes. The values mentioned in these studies were greatly varied even for the same breed (636±270 for local buffalo and 636±159 for Murrah). However, when comparing the available values for different breeds, the calving interval of the local breed seems to be remarkably higher than that of the exotic breeds and their crosses (626 days vs 505 days).Age at first calving in buffaloes was influenced by the breed of buffalo, and their lactation number also varies with the influence of the year of calving, dry period, sex of the calf, the season of calving, and year of dry off (Charlini and Sinniah, 2015).

The dry period is the stage when buffaloes stop producing milk and it also varies with the type of breed. Longer dry periods affect economically to farms. The normal dry period of buffalo varies between 2-3 months (TNAU, 2009). The study results showed that the lactation length of buffaloes goes beyond 6 months (Table 9) and can be improved by optimum management practices; controlled breeding or rigorous culling (Charlini and Sinniah, 2015). The research by Charlini and Sinniah (2015) was the only study from selected literature that aimed to explore all the above-mentioned milk production characteristics in buffaloes by their breed. So buffalo milk production characteristics are not explicitly considered by existing literature and are therefore an opportunity for future research.

Comparative Studies Reporting Composition of Buffalo Milk with Milk from Other Species

Among the selected publications, the studies of Mahanama, (2008) compared the milk composition of buffalo milk with that of cattle, goat, and ewe's milk under local conditions. Results are summarized in Table 10. Results showed that buffalo milk contains a considerably higher amount of butterfat (7.28%) compared to that of cattle (4.08%) and goats (4.3%). However, it is slightly lower than that of the ewe's milk (7.5%). The protein content of the buffalo milk (4.15%) was higher than that of cattle (3.24%) and goat (3.9%) but lower than that of the ewe's milk (6.0%). Both buffalo milk and cattle milk contain almost the same levels of lactose (4-6-4.7%). In contrast, both goat milk and ewe's milk contain higher amounts of lactose (5.8% and 5.4%, respectively). The total solid content of the milk has great importance in the yield of milk curd, the higher the milk solid content, the higher the yield of the milk curd. Compared to cow milk, buffalo milk contains approximately 40% more total solids than cow milk and goat milk which is advantageous in curd production as buffalo milk produces more curd yield than that from cow milk. Milk composition is reported to vary according to the species of the animal, feeding management, health status of the animal, environmental factors, and stage of lactation (Mahanama, 2008). The composition of buffalo milk can also vary with the method of milking and individual variations (Hallqvist, 2019).

Hallqvist (2019) compared the lactation performance of buffalo and cattle reared under local conditions (Table 11). Results showed that the buffaloes have poor lactation performance compared to cattle as buffaloes have smaller lactation length (8.7 months), longer dry period (4.33 months), and longer calving interval (16.5 months), delayed age at first calving (50 months) and with lower milk yield (2100 kg/lactation) than cattle.

Buffalo Milk Products

Buffalo milk is considered suitable for the production of a range of dairy products such as curd, butter, butter oil, soft cheese, condensed or evaporated milk, ice cream, and yoghurt due to the milk richness in buffalo milk (Kanakkahewage *et al.*, 2016). Milk and milk products made with buffalo milk give a rich flavor because of its high fat and total solids content, which can be marketed for a higher price than manufacturing from cow milk. Higher levels of total solids in buffalo milk provide a unique texture and better gel consistency to yoghurt (Yapa *et al.*, 2020; Hettige *et al.*, 2013). Curd is the main product that comes out of buffalo milk

and the best-graded paneer by texture and appearance is said to be made with buffalo milk (Jayawickrama *et al.*, 2008; Silva, 2009; Priyashantha *et al.*, 2021). Recently, there has been an increasing trend of diversifying buffalo milk products and this can be noted by a higher number of publications within the last decade.

The vast majority (~70%) of the selected literature for the current review had focused on buffalo milk products. There is a tendency to manufacture dairy products from buffalo milk due to its higher contents of total solids and nutrients (Hettige *et al.*, 2013). The frequency of studies on buffalo milk products in selected studies is depicted in Figure 3. Curd is the most popular dairy product produced from buffalo milk followed by cheese, yoghurt, and paneer. It should be noted that just over 50% of the studies have been dedicated to curd. Unfortunately, the practice of preparing diversified products from buffalo milk is not commonly practiced on buffalo farms in Sri Lanka. Though curd and yoghurt are manufactured at the commercial level, valuable milk products such as cheese and butter are not in the practice of commercial manufacturing (Silva, 2009; Priyadharshanie, 2003). There's a gap in the availability of studies to explicitly understand the characteristics of butter made with buffalo milk.

Buffalo Curd (*meekiri*): Buffalo curd is a traditional fermented dairy product in Sri Lanka made by coagulating fresh buffalo milk using lactic acid bacteria to convert lactose in milk to lactic acid. The technology, microbiology, and quality characteristics of the traditional Sri Lankan buffalo curd have comprehensively been reviewed in recent literature (Priyashantha *et al.*, 2021). Results from the selected publications suggest that the acceptable levels of milk fat, milk-solid non-fat, and the pH of the buffalo curd are 7.5%, 8.5%, and 4.5, respectively (Weerasekara *et al.*, 2010; Andersson, 2019). It has also been noted that the E. coli counts should be zero in 1 g of the product. Curd can also be made from cow milk and those made from cow milk are termed "*deekiri*". However, there is a significant difference in product quality between *meekiri* and *deekiri*. *Meekiri* is whiter, slightly firmer, and sourer in taste, and has a higher fat content than *deekiri* (Andersson, 2019; Hallqvist, 2019).

Buffalo cheese: In comparison to cheese made from cow's milk, buffalo milk cheese has considerably higher nutritional value because of its high levels of fat, protein, lactose, minerals, and vitamins (Priyadharshanie, 2003). Studies by Erambamurthy (2013) and Pagthinathan and Nafees (2016) aimed to develop cheddar cheese from low-fat buffalo milk and evaluate its quality. According to both studies, an average yield of 720g/5.0 L and 515g/5.0 L of full cream cheese and low-fat cheese was obtained with an increment in fat content during the ripening period (Erambamurthy, 2013) while the moisture content and protein content were decreased. Cheddar cheese made with full cream was superior in colour, flavour, taste, and texture but low-fat cheese had higher hardness. Based on these results, the authors concluded that the fat level composition significantly affects the sensory quality and acceptability of cheddar cheese made with buffalo milk.

In another study, Priyadharshanie (2003) studied the production of semi-hard cheese; namely Gouda cheese from buffalo milk, and the final product had an acceptable level of moisture content (52.7%). Gouda cheese can be made with buffalo milk to obtain similar consumer acceptability for colour and appearance to Gouda cheese made with cow's milk; but aroma, flavour, and texture can be changed according to the conclusions of the study (Priyadharshanie, 2003). According to Ratnasingh (2008), mozzarella is the ideal cheese that can be made with buffalo milk. As mentioned by Walisinghe *et al.* (2018), the chemical composition of mozzarella cheese was affected by starter culture as well as the type of milk. The type of milk affects the yield and colour of mozzarella cheese. The unique chemical composition of buffalo milk significantly affects its quality. Based on the above results, it can be concluded that cheese can be manufactured from buffalo milk with similar qualities to cheese made from cow's milk.

Studies Focused on Improvement of Product Characteristics

Out of the total studies selected in the current study, 25 studies (~53%) explored improvements in buffalo milk products in the means of improving sensory, nutritional, microbial, textural, and compositional properties. Out of these studies, most have focused on the improvement of sensory properties in buffalo milk products; in particular, the appearance, colour, aroma, and taste as consumer preferences were mostly towards those sensory properties (Fig. 04). Of the 25 studies that explored improvements in buffalo milk products, 3 studies explored more than one property in milk products.

Studies focused on curd: Both sensory properties and microbial properties were the most researched properties for improvements in the product characteristics of buffalo milk curd. Preparation of

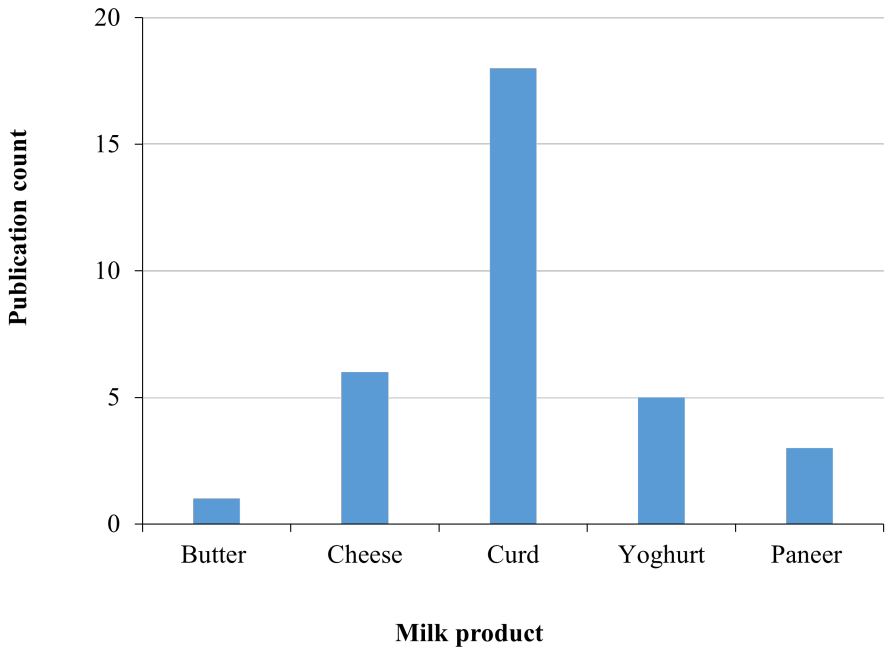

Figure 3: Number of publications selected for the current review that include buffalo milk products

Table 10: Comparison of milk composition and some chemical properties of buffalo milk with milk of other species in Sri Lanka

Species	Water %	*Total solids %	Protein %	Fat %	Lactose %	Mineral salts %	Milk solid nonfat %	Acidity%	pH
Buffalo	82.2	17.8	3.5 - 4.8	7.1 - 7.5	4.7	0.8	9.43	0.13	6.4
Cattle	87.5	12.5	3.2 - 3.3	3.7 - 4.5	4.6	1	8.27	0.18	6.5
Goat	86.5	13.5	3.9	4.3	5.8	0.8			
Ewe	80.9	19.1	6.0	7.5	5.4	1.1			

Table 11: Comparison of milk production characteristics in buffalo with other species (Reference: Hallqvist (2019))

Species	Lactation length (months)	Dry period (months)	Age at first calving (months)	Calving interval (months)	Milk yield (kg/lactation)
Buffalo	8.7	4.33	50	16.5	2100
Cattle	10	2.5	27	12.5	6500

buffalo curd by incorporating treacle (Jayasundara, 2012), natural mango (Perera *et al.* 2013), and the pulp and dried pieces of mango (Bowatte *et al.*, 2015) have been studied to improve the sensory properties of ordinary curd. Buffalo curd incorporated with 20% (w/w) treacle and 2% (w/w) gelatin was reported to have the highest sensory scores for appearance, flavour, and colour (Jayasundara, 2012). It also had a shelf life of 15 days in refrigerated conditions (4 °C). The incorporation of 50% mango pulp was the best combination in terms of flavour and overall acceptability (Perera and Ranadheera, 2013). Another study revealed that the incorporation of the pulp and dried pieces of mango (variety Karthakolomban) at a level of 8% received the highest scores for organoleptic properties (Bowatte *et al.*, 2015). The addition of probiotic bacteria is also seen as a means to improve the sensory properties of the buffalo curd. For example, one study revealed that incorporation of bifidobacteria resulted in higher scores for certain sensory attributes such as taste and mouthfeel compared to conventional curd without bifidobacteria (Jayamanne and Samarajeewa, 2011).

The use of starter culture or inoculum is crucial in curd making as it affects the curdling properties as well as the properties of the final product. Recent research conducted on curd starter cultures revealed that the

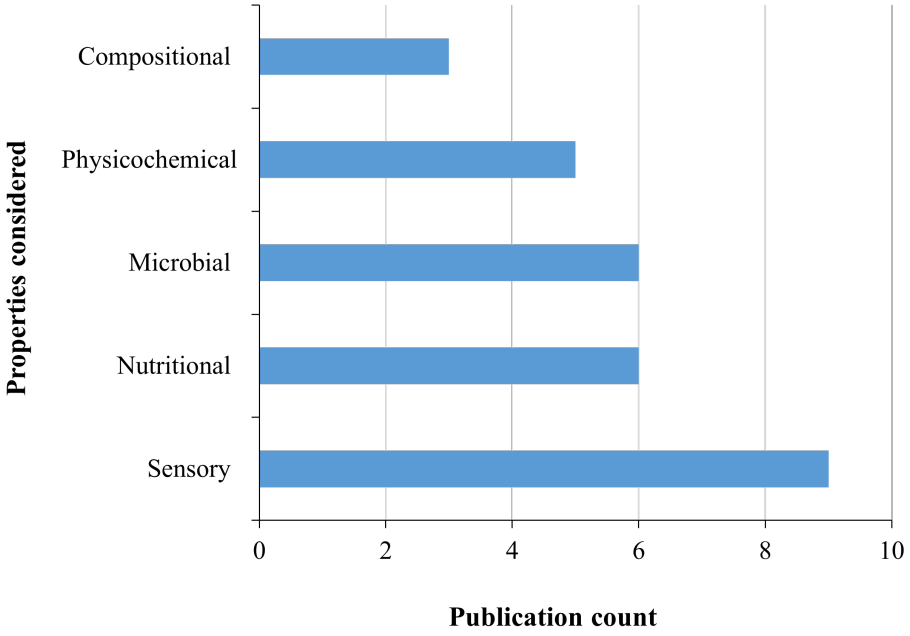

Figure 4: Different properties in buffalo milk products considered

effect of using different types of starter cultures does not affect the pH of the final product. Therefore, there is a possibility of making high-quality curd with buffalo milk, independent of the starter culture (Andersson, 2019). As the starter cultures are expensive; a small amount of curd from a previous batch is commonly added in preparation of curd (Priyashantha *et al.*, 2021). However, this may have differences in microbial composition and may affect the final product quality in serial production. To minimize the cost of starter cultures, several authors have suggested alternatives to conventional starters used for curd making.

Other than the improvement in sensory attributes of curd, several other studies have focused on the probiotic properties of microorganisms used in curd manufacturing, suppression of pathogenic microorganisms in curd, and reduction of syneresis in curd. *Lactiplantibacillus plantarum* (formerly *Lactobacillus plantarum*), *Levilactobacillus brevis* (formerly *Lactobacillus brevis*), and *Lactobacillus delbrueckii lactis* have been identified as the predominant lactobacilli found in curd (Sandarenu *et al.*, 2017). The probiotic properties of these microorganisms have been extensively studied (Rajapakshe *et al.*, 2014; Sandarenu *et al.*, 2017; Shuhadha *et al.*, 2017). As buffalo milk curd is a fermented product, it may have properties to suppress pathogenic microorganisms largely due to the production of antimicrobial compounds during fermentation and storage. *Listeria monocytogenes* is a food-borne pathogen reported to inhabit higher extents in milk and milk products compared to other foods. Fermentation has been identified as an effective tool in eliminating *Listeria* from buffalo milk, as *Listeria* was not detected in curd, and the consumption of buffalo curd is said to be safe for human listeriosis (Jayamanne and Samarajeewa, 2011).

Studies focused on yoghurt: Sensory properties were predominant in the studies relevant to improving the product characteristics of buffalo yoghurt. Improving the product characteristics by incorporating fruit material is a greater concern among researchers and results in varying effects. The addition of 5% avocado puree into a buffalo milk yoghurt was preferred in the sensory evaluation (Hettige *et al.*, 2013). On the other hand, Yapa *et al.* (2020) evaluated a bael fruit pulp-enriched probiotic buffalo yoghurt. They found that bael fruit had a negative impact on the aroma. However, mean scores for taste, after-taste, and mouthfeel attributes had no significant effect. Whereas, the addition of 5% (w/v) bael fruit pulp received higher scores for appearance. The results further showed that the addition of the probiotic *Lacticaseibacillus rhamnosus GG* had significantly reduced the post-acidification and the syneresis of the products, and the products maintained probiotic counts of $>10^7$ CFU/mL throughout the storage (21 days at 4 ^{0}C) suggesting that buffalo milk yoghurt is an ideal matrix to deliver probiotics at higher viability. The addition of bael also had a positive effect on decreased syneresis rates. Not only did the addition of probiotics have positive effects on the product quality, but also the addition of prebiotics had positive effects. For example, inulin-incorporated buffalo yoghurt (2% w/v) showed higher consumer acceptability and probiotic stability and also improved microbiological, sensory, and viscosity

(Gnanarathna *et al.*, 2018).

As buffalo yoghurt is commonly made with unhomogenized milk, the gel structure in milk products is more porous with a large number of larger fat globules leading to a higher degree of syneresis. Abesinghe *et al.* (2020b) showed that ultrasonicated or shear homogenized buffalo milk gels showed higher gel strength and consequently resulted in superior gelation properties in yoghurt due to the downsizing of buffalo's milk fat globules.

Studies focused on cheese: As firmness and texture are important factors in the preparation of different types of cheese such as hard cheese, semi-hard cheese, and soft cheese; further improvements have been explored in physicochemical properties. All types of cheese have been researched in the literature from buffalo milk. To improve sensory properties; ingredients that enhance colour, flavour, and nutritional value have been incorporated with buffalo milk and processed to get the required value-added product from buffalo milk products. Mahanama (2008) studied adding papaya pulp to improve fruit cheese from buffalo milk. The product contained dry matter (23.73%), average moisture content (75.06%), crude protein (9.7%), and fat (14.03%) levels which were in recommended levels of dry matter (20-45%) and moisture (55-80%). As mozzarella cheese is added to pizza, mint flavour is a desirable flavour. In consideration of that, Ratnasingh (2008) researched the incorporation of mint leaf extract with buffalo milk in the manufacture of mozzarella cheese. The final product was creamy white in colour and sweet in taste. According to studies by Erambamurthy (2013), and Pagthinathan and Nafees (2016), full cream cheddar cheese was preferred in colour, flavour, texture, and taste to low-fat cheddar cheese made from buffalo milk.

Studies focused on paneer: Paneer is prepared by heat and acid coagulation of buffalo milk and these processing conditions have varying effects on textural properties. Dishiwarthani *et al.* (2018) studied the effect of coagulation temperature and the usage of different coagulants. As explored by Dishiwarthani *et al.* (2018) when coagulation temperature increased up to 90 ^{0}C hardness and cohesiveness increased and springiness increased up to 80 ^{0}C and decreased when increasing the temperature further. It was also found that at a coagulation temperature of 80 ^{0}C, it had higher acceptability. According to the research conducted by Jayawickrama *et al.* (2008), buffalo whole milk paneer was graded as the best in comparison to paneer made from cow milk, skim buffalo milk, and skim cow milk.

Studies focused on butter: Unlike other dairy products originating from buffalo milk, butter has received less attention from researchers. There was only a single study focused on the improvement of product quality of butter and this has reported the production of herbal butter using Gotukola (*Centella asiatica*) extract. The final product was reported to reach consumer acceptability and was cost-effective (Silva, 2009).

CONCLUSION

This review found that there is an increasing trend of publications relevant to buffalo milk production in Sri Lanka over the last decade. The majority of the publications originated from Sri Lanka on buffalo milk (~60%) have focused on product development and improvement aspects rather than production aspects of buffalo milk.

Less attention has been paid to investigating the breed differences in milk composition, yield improvements, and regional differences in milk production. Therefore, there is a research gap in identifying the production characteristics of different buffalo breeds in terms of lactation performance, average daily milk yields, and milk compositions. Of those studies dedicated to buffalo milk products, most have focused on buffalo milk curd and cheese. Thus, the diversification of buffalo milk products was not commonly practiced on farms where buffaloes are reared and at the commercial level. But production of butter, cheese, yoghurt, and paneer from buffalo milk was researched in existing studies. Thus more attention to diversification of milk products coming from buffalo milk is needed on the farm, commercial level, and as a cottage industry.

Local buffaloes, Murrah, and their crossbreeds were the most studied buffalo breeds, reared mainly in the dry zone and intermediate zone of the country. The dry period of buffaloes goes beyond 6 months which is more than their expected dry period of 2-3 months. Therefore, significant yield improvement can be possible by decreasing the dry period. The lactation length of the exotic breeds is almost as double that of the local breed. Murrah and Murrah crossbreeds show the highest average daily milk production in Sri Lanka and the milk production of the local buffalo can greatly be improved by incorporating exotic genetics through suitable crossbreeding programs.

More research on regional differences in buffalo milk production would be useful to get a comprehensible understanding of the suitable climatic conditions and agro-climatic zones for buffalo milk production. Studies on yield improvements would be helpful to

improve production and more profits, and thereby inspire farmers for buffalo production. More research on milk composition and yields in buffalo breeds can assist in identifying the most suitable breed of buffalo suitable for Sri Lanka. So further research should be undertaken to investigate these aspects and also buffalo milk production characteristics.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships influencing the work reported.

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REFERENCES

Abesinghe, A.M.N.L., Priyashantha, H., Prasanna, P.H.P., Kurukulasuriya, M.S., Ranadheera, C.S. and Vidanarachchi, J.K. (2020a). Inclusion of Probiotics into Fermented Buffalo (*Bubalus bubalis*) Milk: An Overview of Challenges and Opportunities. *Fermentation*, 6(4), 121p. DOI: https://doi.org/10.3390/fermentation6040121.

Abesinghe, A.M.N.L., Vidanarachchi, J.K., Islam, N., Prakash, S., Silva, K.F.S.T., Bhandari, B. and Karim, M.A. (2020b). Effects of ultrasonication on the physicochemical properties of milk fat globules of *Bubalus bubalis* (water buffalo) under processing conditions: A comparison with shear-homogenization. *Innovative Food Science and Emerging Technologies*, 59, 102237. DOI: https://doi.org/10.1016/j.ifset.2019.102237.

Andersson, C. (2019). Impact of starter culture on curd manufacture – one of the most commonly consumed fermented milk products of Sri Lanka. Bachelor Thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden. Retrieved from https://stud.epsilon.slu.se/15212/.

Beallslist. (2017). Beall's List of Potential Predatory Journals and Publishers. Retrieved from https://beallslist.net/.

Bandara, A. (1993). Livestock in the Small Farms of Systems B and C of the Mahaweli Project. *Journal of the National Science Foundation of Sri Lanka*, 21(2), 195-199. DOI: http://doi.org/10.4038/jnsfsr.v21i2.8103.

Bowatte, W.M.S.P., Gunasekara, D., Senadeera, P., Chandrasekara, A., Prasanna, P.H.P. and Lakmini, G.W.A.S. (2015). Development of Buffalo Milk Curd Incorporated with Pulp and Dried Pieces of Mango. In: *Annual Research Symposium Proceedings*. Mihintale: Rajarata University of Sri Lanka, 40p.

Brennan, L., Langley, S., Verghese, K., Lockery, S., Ryder, M., Francis, C., Phan-Le, N.T. and Hill, A. (2021). The role of packaging in fighting food waste: A systematized review of consumer perceptions of packaging. *Journal of Cleaner Production*, 281, 125276p. DOI: https://doi.org/10.1016/j.jclepro.2020.125276.

Charlini, B.C. and Sinniah, J. (2015). Performance of Murrah, Surti, and Nili-Ravi buffaloes and their crosses in the intermediate zone of Sri Lanka. *Livestock Research for Rural Development*, 27(3).

DAPH. (2019). Livestock Statistical Bulletin 2019. Department of Animal Production and Health, Peradeniya, Sri Lanka. Available at: Retrieved from http://www.daph.gov.lk/web/images/content_image/publications/StatisticalBulletin2019-2020.10.06-compressed.pdf.

Dematawewa C.M.B. and Dekkers, J. C. M. (2014). Lactation curve modeling for Murrah and Surti buffalo breeds in Sri Lanka. In: 10th World Congress of Genetics Applied to Livestock Production. American Society of Animal Science, Vancouver, BC, Canada. 50-52. Retrieved from https://www.asas.org/docs/default-source/wcgalp-posters/449_paper_9871_manuscript_1039_0.pdf?sfvrsn=2.

Dishiwarthani, T., Mudannayake, D.C., Mangalika, U.L.P. and Jayawardana, J.M.D.R. (2018). Effect of Coagulation Temperature on Yield, Chemical, Sensory and Textural Properties of Buffalo Milk Paneer. In: *International Research Symposium of UWU-2018*. Uva Wellassa University, Badulla, Sri Lanka. 294p.

Erambamurthy, S. (2013). Development of Cheddar Cheese Using Low Fat Buffalo Milk. Bachelors Thesis, Faculty of Agriculture, Eastern University, Chenkalady, Sri Lanka.

FAOSTAT. (2022). Crops and livestock products: Artichoke. [online] Food and Agriculture Organization of the United Nations, Rome, Italy. https://www.fao.org/faostat/en/#data/QCL/visualize.

Gnanarathna, K.A.D.C., Chandrasekara, A., Senadeera, P., Gunasekara, D.C.S., Weerasingha, W.V.V.R. and Prasanna, P.H.P. (2018). Probiotic Effect of Inulin Incorporated Set Yoghurt Prepared Using Cattle and Buffalo Milk. In: *10th Annual Research Symposium Proceedings*. Rajarata University of Sri Lanka, Mihintale, Sri Lanka. 46p. Retrieved from http://repository.rjt.ac.lk/handle/123456789/2054.

Hallqvist, J. (2019). The Importance of Buffalo Milk in the Curd Manufacture of Sri Lanka. Independent Project Report, Swedish University of Agricultural Science, Uppsala, Sweden. Retrieved from https://stud.epsilon.slu.se/14747/7/hallqvist_j_190703.pdf.

Hettige, K.D.T., Ranadheera, C.S., Jayawardana, N.W.I.A. and Vidanarachchi, J.K. (2013). Quality Evaluation of Avocado Fruit Yoghurt Made from Buffalo Milk. In: *Annual Research Symposium Proceedings*. Rajarata University of Sri Lanka, Mihintale, Sri Lanka. Retrieved from http://repository.rjt.ac.lk/bitstream/handle/123456789/480/28.pdf?sequence=1.

Hitihamu, S. and Epasinghe, S. (2015). Socio-economic condition of dairy industry in Mahaweli H area. Hector Kobbekaduwa Agrarian Research and Training Institute, Colombo 07, Sri Lanka. Retrieved from http://www.harti.gov.lk/images/download/reasearch_report/new1/184.pdf.

Horadagoda, A. (1990). Studies on the Composition of Indigenous Buffalo Milk in Sri Lanka. Ph.D. Thesis, University of Peradeniya, Peradeniya, Sri Lanka.

Ibrahim, M.N.M. and Jayatileka, T.N. (2000). Livestock Production under Coconut Plantations in Sri Lanka: Cattle and Buffalo Production Systems. *Asian-Australasian Journal of Animal Sciences*, 13(1), 60–67.

Jayamanne, V. and Samarajeewa, U. (2011). Evaluation of the effects of fermentation of buffalo curd and acidity on survival kinetics of *Listeria monocytogenes*. *Tropical Agricultural Research and Extension*, 13(4), 94 - 98.

Jayasundara, R.M.N.D. (2012). Development of a Treacle (*Caryota urens*) Incorporated Buffalo Curd with Improved Preferability and Sensory Properties. Thesis, Uva Wellassa University, Badulla, Sri Lanka. Retrieved from http://www.erepo.lib.uwu.ac.lk/handle/123456789/6128.

Jayawickrama, N.K.K.S., Mangalika, U.L.P. and Adikari, A.M.J.B. (2008). Preparation of "Paneer" from Cow and Buffalo Milk with Different Fat Levels. In: Annual Research Symposium Proceedings. Rajarata University of Sri Lanka, Mihintale, Sri Lanka, 36–41.

Kanakkahewage, M., Jasinghe, O., Sujani, S. and Seresinhe, T. (2016). Effect of Supplementation of Different Concentrate Rations on Weight Gain, Milk Yield, and Composition of Cross-Bred Buffalo Cows. In: Proceedings of International Seminar on Livestock Production and Veterinary Technology. Indonesian Center for Animal Science Research and Development (ICARD), Bogor, Indonesia, 122–126.

Mahanama, N. (2008). Manufacture of Fruit cheese from Buffalo Milk and Papaya Pulp Manufacture of Fruit cheese from Buffalo Milk and Papaya Pulp. Master's Thesis, University of Sri Jayewardenepura, Nugegoda, Sri Lanka. Retrieved from http://192.248.32.11/bitstream/handle/123456789/5412/Manufacture%20of%20fruit%20cheese%20from%20buffalo%20milk%20and%20papaya%20pulp-001-015.pdf?sequence=5&isAllowed=y.

Malcolm, M.B.J.G.R., Jayasinghe, J.M.P., Rathnayake, R.M.S.D. and Samaraweera, A.M. (2019). Production characteristics and technical efficiency of buffalo farming in Thanamalwila veterinary division, Sri Lanka. *Sri Lanka Journal of Animal Production*, 11, 16–22.

Mohamed, N. and Jeyamalar, R. (2005). Performance Analysis of Dairy Cattle and Socio-Economic Analysis of Dairy Cattle Farmers in Trincomalee District. In: Proceedings of the Annual Research Sessions - 2005. Eastern University of Sri Lanka, Chenkaladi, Sri Lanka. 230 - 240.

Pagthinathan, M. and Nafees, M.S.M. (2016). Production and evaluation of low-fat cheddar cheese using buffalo milk. *International Journal of Agriculture, Forestry and Plantation*, 4, 97–106.

Perera D.K.J.K., Ranadheera C.S. and J.N.W.I.A. (2013). Development of Natural Mango Layered Buffalo Curd. In: Annual Research Symposium Proceedings. Rajarata University of Sri Lanka, Mihintale, Sri Lanka. 91p.

Premathilaka, S., Seresinhe, T. and Gajaweera, C. (2016). Socio-economic Characteristics of Small Scale Buffalo Farms in Tanamalwila Area in Moneragala District of Sri Lanka. In: Proceedings of International Seminar on Livestock Production and Veterinary Technology. Indonesian Center for Animal Science, Bogor, Indonesia. 198–203. DOI:https://doi.org/10.14334/Proc.Intsem.LPVT-2016-p.198-203.

Priyadharshanie, W.Y.P. (2003). Production of a Buffalo Milk Cheese. [online] Available at: http://suslrepo.nsf.ac.lk/handle/1/106.

Priyashantha, H., Ranadheera, C.S., Rasika, D.M.D. and Vidanarachchi, J.K. (2021). Traditional Sri Lankan fermented buffalo (*Bubalus bubalis*) milk gel (Meekiri): technology, microbiology and quality characteristics. *Journal of Ethnic Foods*, 8(27), 1-17. DOI: https://doi.org/10.1186/s42779-021-00105-4.

Rajapakshe, R.P.N.N., Brasathe, J., Wijesinghe, D.G.N.G. and Chandrasekara, A. (2014). Assessing the Probiotic Effect of Buffalo Milk Curd. In: Proceedings of the Faculty of Agriculture Undergraduate Research Symposium year. Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka. 76p.

Ranasinghe, K.K.K., Hirimuthugoda, N.Y., Rajapakse, R.P.V.J. and Gunawardane, A. (2017). Milk protein polymorphism of buffaloes in southern Sri Lanka. *Journal of the University of Ruhuna*, 5(2), 2345–9387. DOI: http://doi.org/10.4038/jur.v5i1-2.7890.

Ratnasingh, M. (2008). Production of Mozzarella Cheese with Mint Flavour Using Buffalo Milk. Master's Thesis, University of Sri Jayewardenepura, Nugegoda, Sri Lanka. DOI:10.31357/fapsmst.2008.00520.

Sandarenu, M.W.A.K., Rajawardana, D.U. and Fernando, K.M.E.P. (2017). Probiotic Potential and Antibiotic Resistance of Lactic Acid Bacteria Isolated from Curd in Sri Lanka. *International Journal of Multidisciplinary Studies*, 4(2), 9-21. DOI: https://doi.org/10.31357/ijms.v4i2.3376.

Shuhadha, M.F.F., Panagoda, G.J., Madhujith, T. and Jayawardana, N.W.I.A. (2017). Evaluation of probiotic attributes of *Lactobacillus* sp. isolated from cow and buffalo curd samples collected from Kandy. *Ceylon Medical Journal*, 62(3), 159-166. DOI: http://doi.org/10.4038/cmj.v62i3.8519.

Silva, N.A.D. (2009). Preparation of herbal butter by using buffalo milk. Master's Thesis, University of Sri Jayawardenepura, Nugegoda, Sri Lanka. DOI:10.31357/fapsmst.2009.00516.

TNAU. (2009). Animal Husbandry - Buffalo - Milk Production. https://agritech.tnau.ac.in/animal_husbandry/animhus_buffalomilking.html#:~:text=maximummilkyield.-,Dryperiod,3monthsbeforeexpectedcalving.

Walisinghe, W.M.N.N., Mudannayake, D.C., Yatinuwara, G.Y.G.S. and Palliyeguru, M.W.C.D. (2018). Effect of Starter Culture and Type of Milk on Textural and Functional Properties of Mozzarella Cheese. *International Research Symposium of UWU-2018*. Uva Wellassa University, Badulla, Sri Lanka. 285p.

Weerasekara, W.M.S.I.M., Karunarathne, G.M.C.R. and Prathapsinghe, G.A. (2010). Assessment of Quality Parameters in Curd and Yoghurt of Small Scale Processors in North Central Province. *Wayamba Journal of Animal Science*, 12, 26-29.

Yapa D., Jithmi S, WeerathilakeD., R.M.D., 2020. Microbial, Physiochemical and Sensory Properties of Bael (*Aegle marmelos*) incorporated Buffalo Milk Yoghurt containing *Lb. rhamnosus* GG. 1–16. DOI: https://doi.org/10.20944/preprints202012.0213.v1.