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REVIEW ARTICLE

The Philippine Dairy Industry: Status, Key Influences, Benchmarks, and Strategies for Improvement

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ABSTRACT

The Philippine dairy industry is an emerging sector with significant challenges and promising opportunities. With a growing population and expanding middle class, the demand for dairy products is rising. However, local production accounts for only 1% of domestic requirements, indicating heavy reliance on imported dairy products. The industry is primarily composed of smallholders who comprise the majority of dairy farmers and play a crucial role. This review paper aims to evaluate the current status of the Philippine dairy industry by analyzing industry trends, challenges, and opportunities through a comprehensive literature review of industry reports, research studies, published books and articles, and to provide recommendations for improvement based on successful practices from neighboring countries like India, Taiwan, and Thailand. The Philippines falls behind these countries in milk yield per capita per day and self-sufficiency. Factors influencing this performance include government support, market demands, infrastructure, and adoption of advanced technologies. By addressing these critical areas such as breeding and reproduction, nutrition, capacity building, digitalization, and policy support, the Philippines can enhance its dairy production, improve the livelihoods of local farmers, address malnutrition, and reduce dependence on imports. Harmonization of programs and collaboration among government agencies, research institutions, private sector, and other stakeholders are critical to achieving sustainable growth in the dairy industry.

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Keywords: Asian countries, dairy industry, dairy technologies, tropical, Philippine dairy

Abbreviations: AI, artificial insemination; BADACO I, Batangas Dairy Cooperative I; BAI, Bureau of Animal Industry; BCDFI, Batangas Christian Dairy Foundation Inc.; BEF, bovine ephemeral fever; CDA, Cooperative Development Authority; CGIAR, Consultative Group for International Agricultural Research; COA, Council of Agriculture; DA, Department of Agriculture; DA-BAR, Department of Agriculture - Bureau of Agricultural Research; DAHD, Department of Animal Husbandry and Dairying; DepEd, Department of Education; DIPA, Dairy Herd Improvement Programme Actions; DLD, Department of Livestock Development; DMG, Dutch Mill Group; DOST-PCAARRD, Department of Science and Technology - Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development; DPO, Dairy Farming Promotion Organization; DTI, Department of Trade and Industry; ET, embryo transfer; FAO, Food and Agriculture Organization of the United Nations; HMI, Hacienda Macalauan Inc.; HTST, High-Temperature, Short-Time; ICAR, Indian Council of Agricultural Research; INAPH, Information Network for Animal Productivity and Health; KKMI, Katipunan ng mga Kooperatibang Maggagatas Inkorporada; LN, liquid nitrogen; LSD, lumpy skin disease; MOA, Ministry of Agriculture; MPAV, Metro Pacific Agro Ventures, Inc.; MPIC, Metro Pacific Investments Corp.; NDA, National Dairy Authority; NDDB, National Dairy Development Board; NDRI, National Dairy Research Institute; PAGASA, Philippine Atmospheric, Geophysical and Astronomical Services Administration; PCC, Philippine Carabao Center; PCL, Public Company Limited; PCRDC, Philippine Carabao Research and Development Center; PDC, Philippine Dairy Corporation; PRDP, Philippine Rural Development Project; SMC, San Miguel Corporation; SMDFCM, Sta. Maria Dairy Farmers' Cooperative Marketing; SSF, Shared Service Facilities; SSG, Special Safeguard; SWOT, Strengths, Weaknesses, Opportunities, and Threats; TAP, Traceability/Good Agricultural Product; TMR, Total Mixed Ration; TRQ, Tariff Rate Quota; UHT, Ultra-High Temperature; UNDP, United Nations Development Program; UP, University of the Philippines; UPLB-CAFS-DTRI, University of the Philippines Los Baños - College of Agriculture and Food Science - Dairy Training and Research Institute; USDA FAS, United States Department of Agriculture - Foreign Agricultural Service

I. INTRODUCTION

Dairy production plays a vital role in agriculture, generating jobs in several sectors such as farms, milk transport, processing, agricultural supplies, and service areas (Douphrate et al. 2013). Currently, the Philippine dairy industry faces several challenges, particularly on the dispersed smallhold farms in rural areas resulting in difficulty in milk collection, accessibility to processing centers, and other related dairy activities. Moreover, many farmers do not own land leading them to rely on crop residues and available fodders (Oliveros 2019). The country's tropical climate, characterized by high temperatures, high humidity, and abundant rainfall, further aggravates these challenges. Hence, effective dairying requires good management practices to mitigate problems like heat stress, which reduces milk production.

Although local milk supply has improved due to an increase in the number of dairy animals and greater milk production efficiency, the country's dairy industry meets only 1% of the annual milk requirement. Its growth remains constrained by insufficient support and minimal investments (Mojica-Sevilla 2023). Dairy production is labor-intensive, and challenges such as required capital investment and limited access to local markets persist. However, the industry provides employment opportunities and a steady income for agricultural workers, despite their limited control over production and marketing processes (Douphrate et al. 2013).

On the other hand, dairy-producing countries like India, Thailand, and Taiwan present valuable models for growth and sustainability in the dairy sector. These countries have scaled up farm operations boosting the rural economy. Specifically, India, the world's largest milk and buffalo producer provides insights into decentralized production and efficient milk collection systems. Meanwhile, Thailand excels in market development and policy implementation with past collaborations significantly benefiting Philippine dairy stakeholders. Additionally, Taiwan, known for its advanced dairy technologies, offers a blueprint for mechanized and sustainable dairy farming. Therefore, understanding the Philippine dairy industry in reference to the management practices, production strategies, and policies implemented by the neighboring countries is important to identify management practices, suitable advanced technologies, and policies that can be adopted to improve the industry.

The objectives of this paper are to: (a) review the status of the Philippine dairy industry and the significant factors

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influencing the industry trends; (b) compare the local dairy industry with those of the neighboring countries with advanced dairying management and technologies; and (c) identify strategies and effective policies that can be adopted and provide recommendations to improve the Philippine dairy industry through a comprehensive literature review of industry reports, research studies, published books, and articles.

II. THE PHILIPPINE DAIRY INDUSTRY

Evolution of Philippine Dairy Industry: Milestones

The Philippine dairy industry has a rich history dating back to the Spanish colonial era with water buffalo milk widely consumed in Luzon and Visayas in traditional dairy products like "*kesong puti*" and "*pastillas*" (Tsuji 2022). A significant turning point for the industry occurred in the early 1900s with the establishment of the first milk processing plants. As domestic production could not keep pace, milk importation began, new processing plants were established, and milk companies started reconstituting imported milk powder to create popular products like Bear Brand and Milkmaid by 1930 to 1940s (NDA 1999).

In response to the expanding industry, the Sta. Maria Dairy Farmers' Cooperative Marketing (SMDFCM) sought assistance from the Australian government for milk pasteurizing equipment in 1946 and was granted in 1950 which provided a significant boost to their operations. Additionally, several companies including Consolidated Dairy Products, General Milk Company, Darigold Milk Company, and Grassland Farms Inc. established milk processing facilities. With technical support from American parent companies, these plants implemented modern techniques which resulted in the production of new products like canned evaporated milk by Darigold in 1957 (Pe 2011).

To further develop the industry, the Dairy Training and Research Institute (DTRI) was established in 1962 with support from the United Nations Development Program (UNDP). Moreover, other agencies like the Dairy Division of the Bureau of Animal Industry (1964), the Philippine Carabao Center (1993), and the National Dairy Authority (1995) have been instrumental in supporting dairy farmers and boosting local milk production.

Table 1 presents key legislation and policies enacted in recent decades. Notable programs, including the Medium Term Dairy Development Program and the School Milk Feeding Program in 1989 were launched to reduce dependence on imports and enhance nutritional outcomes (NDA 1999).

Table 1. Philippine government laws and policies related to the dairy industry.

Year	Law/Policy	Title / Provisions
1964	Republic Act 4041	An Act to Develop the Dairy Industry Created the Dairy Division of the Bureau of Animal Industry (BAI)
1966	Republic Act 4718	Placed the Dairy Training and Research Institute under the direct supervision and control of University of the Philippines (UP)
1976	*Batasang Pambansa* 21	An Act providing for the accelerated development of the Philippine Dairy industry and for other purposes Created the Philippine Dairy Corporation (PDC) as the lead government dairy agency tasked to carry out the objectives of achieving milk sufficiency, increasing farmer's income, and conservation of foreign reserves (DA BAR 2022)

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Year	Law/Policy	Title / Provisions
1993	Republic Act 7307	Known as the "*Philippine Carabao Act of 1992*" Created the Philippine Carabao Center (PCC) in 1993 to propagate and promote the Philippine Carabao and for other purposes
1995	Republic Act 7884	Known as the "*National Dairy Development Act of 1995*" Philippine Dairy Corporation (PDC) and Dairy Division of BAI merged to create the National Dairy Authority (NDA) to accelerate the development of the dairy industry in the Philippines, providing for a dairy development fund, and for other purposes.
2013	Republic Act 10611	Known as the "*Food Safety Act of 2013*" Authorized the NDA to be the food safety regulatory agency ensuring food safety in milk production and post-harvest handling
2018	Republic Act 11037	*Masustansiyang Pagkain Para sa Batang Pilipino* Institutionalized a National Feeding Program for Undernourished Children in Public Daycare, Kindergarten, and Elementary Schools
2021	Republic Act 11524	*"Coconut Farmers and Industry Trust Fund Act"*, mandating NDA to promote and provide dairy farming as one of the farm improvement options of the Trust Fund for the benefit of coconut farmers

Current Status of the Philippine Dairy Industry

Products and Forms

In the Philippines, dairy products are sold in liquid and in solid forms. Liquid products include fresh or pasteurized milk, flavored milk, yoghurt, yoghurt-drink, and lacto-juice while cheese, pastillas, milk candy, and milk-o-gel are common solid milk products (Lantican et al. 2017).

Production and Consumption

The volume of locally produced milk has shown gradual increase, from 19,730 mt in 2014 to 28,000 mt in 2023 (Table 2). Although this production represents only about 1% of the country's total annual milk requirement, it suggests notable improvements in production capacity. This improvement in dairy production capacity coupled with increasing consumer preferences for fresh milk pushed the growth in local production (Ang 2017). However, the growth is being limited by challenges in increasing the dairy animal population, due to insufficient funding and minimal investment from the private sector (Mojica-Sevilla 2023).

Simultaneously, the volume of imported milk has been increasing from 1,946,000 mt in 2014 to 3,450,000 mt in 2023, indicating a growing demand for milk products. A further 3% increase in demand is projected in 2024, with imports accounting for the majority (99%) of the supply, showing a significant reliance on external sources to meet domestic demand. The expanding middle class and a rising population, growing from 101.33 million in 2014 to 113.88 million in 2021, are key drivers of the increasing demand for dairy products (Mojica-Sevilla 2023; Ang 2017).

Notably, per capita milk consumption in the country rose significantly with a 7.18% average annual change from 16.99 kg in 2014 to 24.65 kg in 2021 with a corresponding increase in human population (Table 3). The combined increase in human population and per capita milk consumption is likely to further drive demand, and create opportunities for local producers and manufacturers to offer a wider range of dairy products.

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Table 2. Milk supply and demand ('000 MT, LME) in the Philippines, 2014-2023.

Item	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	AAGR (%)
Production	19.73	20.39	21.16	22.76	23.69	24.38	26.71	26.30	30.28	28.00	4.15
Imports*	1,946	1,740	1,793	2,486	2,940	2,970	2,936	3,035	3,351	3,450	7.33
Exports	-	-	-	52	61	66	36	51	109	55	14.32
Consumption	1,966	1,760	1,814	2,457	2,902	2,928	2,927	3,010	3,272	3,423	7.02

**LME- Liquid Milk Equivalent, AAGR – average annual growth rate*
Source: Ang (2017); Mojica-Sevilla (2023)

Table 3. Milk per capita consumption (kg) and human population (million) in the Philippines 2014-2021.

Item	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	AAGR (%)
Milk per capita consumption (kg)	16.99	16.16	21.92	23.55	25.98	28.57	29.27	24.65	6.45	28.00	4.15
Human population (million)	101.33	103.03	104.88	106.74	108.57	110.38	112.19	113.88	1.68	3,450	7.33

**AAGR – average annual growth rate*
Source: Food and Agriculture Organization of the United Nations (FAO 2024) – with major processing by Our World in Data

Table 4. Number of dairy animals in the Philippines, 2014-2023.

Item	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	AAGR (%)
Goat (Does)	976	1,020	2,100	6,820	8,848	9,541	10,357	10,080	13,147	14,908	46.94
Buffalo (Dams)	8,501	8,736	17,800	9,343	9,328	9,328	5,228	6,306	7,120	7,240	5.57
Cattle (Dams)	9,831	10,036	24,500	11,726	10,788	10,595	10,557	9,616	9,949	9,730	8.47
Total	19,308	19,792	44,400	27,889	28,964	29,464	26,142	26,002	30,216	31,878	11.68

**AAGR – average annual growth rate*
Source: Ang (2017); Mojica-Sevilla (2023)

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Population of Dairy Animals

In the Philippines, the number of dairy animals has significantly fluctuated over the years. It increased from 19,308 heads in 2014 to 29,464 heads in 2019, followed by a decline to 26,002 heads in 2021. The numbers rose again, reaching 31,878 heads by 2023 with an average annual change of 12.83% from 2014 to 2023 (Table 4). The initial increase was driven by government herd build-up programs and the growing number of NDA dairy multiplier farms (Ang 2017). The subsequent reduction in the dairy cattle population can be attributed to the culling of older animals and the practice of slaughtering cows for meat. In contrast, the population of dairy goats has been increasing, driven by the NDA's program to import and distribute goats for the livelihoods of small-scale farmers (Mojica-Sevilla 2023).

Key Players and their Roles

The dairy industry in the Philippines consists of several key sectors: (a) the individual smallholder producers; (b) cooperatives; (c) the dairy processors, commercial farms or larger-scale operators; (d) government institutions/ agencies; and (e) private organizations.

Individual Smallholder Producers. Dairy farmers play a key role in shaping the dairy industry market, as they are the primary source of milk production, which forms the foundation of the sector. The quantity and quality of milk are significantly influenced by farm management, nutrition practices, as well as the genetics and overall health of the dairy animals (DA-NDA 2022). Smallholder dairy farmers make up 99.2% (10,484) of the country's 10,563 dairy cattle farmers (DA-NDA 2022). Similarly, 97% of buffalo farms are backyard operations mainly for draft (95%) with only 5% for milk production (FAO 1999). In the goat sector, 98% are backyard farms, though less than 1% of the 3.6 million goats are for dairy (Manalili et al. 2020). Additionally, there are 79 commercial-scale farms, known as Dairy Multiplier Farms (DMFs), that are supported by the NDA. These smallholders typically manage fewer than five cows and caracows, and no more than 35 does (PSA 2023).

Cooperatives. Dairy cooperatives in the country strengthen the dairy industry by providing fresh, high-quality milk and dairy products, access to bigger market networks, promoting food security in the community while considering the income and welfare of the members. In 2023, the NDA provided assistance to 250 primary cooperatives, whose members are natural persons, and six (6) secondary cooperatives, which are composed of primary cooperatives. Additionally, it supported 121 state colleges and universities, local government units, non-government organizations, government state farms, and 1,152 private farms (NDA, 2023). On the other hand, the PCC assists 146 dairy cooperatives and associations of 8,620 carabao owners (PCC 2023). The programs of these cooperatives include the Milk Feeding Programs for undernourished children in partnership with the NDA and the Department of Education (DepEd) in different cities and municipalities (PRDP 2021). These partnerships enable the farmers from rural sites to sell the milk and not be wasted. These cooperatives provide assistance in transforming milk into a diverse range of delightful products such as yogurt, flavored milk (chocolate, strawberry, etc.), pastillas de leche, cheese, kesong puti (white cheese), butter, ice cream, and many more (PRDP 2021; DTI 2022; CDA 2023).

Furthermore, Cuevas and Mina (2022) emphasized the significant role of cooperative membership in enhancing dairy buffalo milk production and marketing. Their study found that cooperative members demonstrated higher technical and marketing efficiencies compared to non-members. Additionally, Palacpac (2010) highlighted that negotiation is a crucial step in promoting active participation among stakeholders and in establishing and maintaining the National Impact Zone (NIZ) network. In this context, the primary cooperative serves as the key entry point, acting as a unified entity that facilitates communication and coordination. Cooperative officials play a critical role as "gatekeepers," representing individual farmers in negotiations with the PCC and other stakeholders within the network. The cooperatives' commitment to excellence and assistance to their members of farm owners and the community is crucial for the country's dairy industry.

Dairy Processors. The dairy processing plants transform raw milk from dairy farmers into a diverse range of products which enhances and ensures the quality and marketability for the consumers (Food and Biotech 2023; FAO 2024). The diversification of products being offered and exploring value-added options contribute to the growth of the dairy industry while ensuring safety of consumers (DA-NDA 2022). Some dairy processing plants include the Liberty Milk Plant,

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the first milk processing plant in the country in 1957, the Hacienda Macalauan Inc. (HMI) and Milka Krem located in Laguna and Nueva Ecija, and those located in Manila are Nestle Philippines, Inc., Century Pacific Food, Inc., Alaska Milk Corporation, San Miguel Food and Beverage, Inc., Aice Brands Ice Cream Philippines, Inc., Unilever RFM Ice Cream, Inc., Yakult Philippines, Inc., and others (Dun & Bradstreet Data Cloud n.d.; DA-NDA 2022).

Government Institutions/Agencies. The major government institutions supporting the industry include the NDA, the Department of Agriculture - Philippine Carabao Center (DA-PCC), and the DTRI at the College of Agriculture and Food Science, University of the Philippines Los Baños. The NDA serves as the central body responsible for managing dairy-related government agency personnel and programs. It acts as the central policy making and directing entity, tasked with ensuring the accelerated development of the industry through policy direction and program coordination and implementation. NDA's major programs include Dairy Herd Build Up Program, Dairy Business Enhancement Program, Milk Feeding Program, and Milk Safety and Quality Assurance Program.

Historically, the PCC was an offshoot of the significant gains achieved from the United Nations Development Programme/Food and Agriculture Organization (UNDP/FAO)-assisted project titled "Strengthening of the Philippine Carabao Research and Development Center (PCRDC)". This project, implemented under the Department of Science and Technology–Philippine Council for Agriculture, Forestry, and Natural Resources Research and Development (DOST-PCARRD), was carried out in two phases from 1982 to 1992. Per DA Administrative Order No. 9, series of 2008, the PCC also serves as the lead institution for livestock biotechnology research and development.

The PCC is mandated with the conservation, propagation, and promotion of the carabao or native buffalo as a source of milk, meat, draft animal power, and hide. The PCC implements the carabao development program, namely: Genetic Improvement Program, Carabao-based Enterprise Development, and Research for Development. Furthermore, the DTRI plays a crucial role in advancing the industry through instruction, research, and extension services. The DTRI is committed to enhancing knowledge dissemination, promoting best practices among farmers, and sharing techniques to improve production efficiencies (DTRI n.d.).

Strengths, Weaknesses, Opportunities and Threats in the Philippine Dairy Industry

The Philippine dairy industry faces numerous internal and external factors that influence its development. The Philippine Dairy Industry Roadmap (2020-2025) presents a comprehensive analysis of the industry that highlights a spectrum of strengths, weaknesses, opportunities, and threats (SWOT) that affect its growth and resilience (Table 5).

Key strengths include supportive legislation like RA 11037, RA 11524, and RA 10611, which have provided significant driving force to the industry. These laws have allocated funds for milk procurement and dairy development under coconut production systems to strengthen local milk production and ensure milk quality. Multiple policies have been enacted to promote self-sufficiency in milk production since 1964. However, local production remains at only 1.3% of demand. This stagnation is attributed to inconsistent policy implementation such as the mislabeling of UHT milk as "fresh milk" in supermarkets, which misleads consumers and, along with other policy gaps, limits market opportunities for domestic dairy producers despite the growing demand for fresh milk (DA-NDA 2022).

Furthermore, the Philippine dairy industry continues to face several challenges including limited dairy animal populations, inadequate feed resources, insufficient investments, and a shortage of skilled labor. The prolonged dry season and lack of feed centers led to insufficient milk production from local livestock which increased the reliance on imports. Farmers struggle to secure quality feed, and while they historically relied on pasture, there is a growing trend of purchasing more expensive feed like corn, wheat, soybean and spent grains. Additionally, rapid urbanization also contributes to the industry's struggles as agricultural lands are being converted into commercial and residential areas. In the 1970s, the country had about 4 million hectares of grassland. At present, less than a million hectares remain, which significantly reduced the available grassland (Hidalgo 2024). Moreover, climate change severely affects both feed availability and animal health (Escarcha et al. 2018). Despite these challenges, the growing consumer awareness of milk's health benefits continues to drive high demand for dairy products.

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Table 5. SWOT analysis of the Philippine dairy industry

STRENGTHS	WEAKNESSES
• Developments in the use of vaccines, antibiotics, anti-parasite drugs and other veterinary medicines • Significant Government support and development programs (RA 11037, RA 11524, RA 10611) • Functional dairy farmers' organizations • Increasing private sector interest/ investment in dairy development • Locally produced milk and milk products compliant to international standard (CODEX) • The presence of NDA and specialized agencies like the PCC, DTRI, PCAARRD spearheading dairy research, development and extension • The genetic improvement of animal breeds improved over the years • Technological advancements	• Limitations in dairy animals • Limited availability of land and feed resources • Capital intensive industry • Low turnout on availment of financing packages offered by lending institutions • Inadequate cold handling facilities from farm to processing center • Inadequate manpower and skills
OPPORTUNITIES	**THREATS**
• Increasing demand on fresh milk and milk products • Growing support to the industry • Bigger Processing Sector- Development of more value-added milk products and bigger opportunities to products such as cheese and ice cream • Increasing dairy awareness of the consuming population • Better distribution channels • Growing prospects of dairying as an alternative livelihood activity	• Climate change • Land conversion • Ageing dairy farmers • Cheaper import substitutes • Anti-milk and meat propaganda campaign

Source: Department of Agriculture - National Dairy Authority, "The Philippine Dairy Industry Roadmap (2020–2025), 2022.

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III. ANALYSIS OF DAIRY INDUSTRIES IN THE PHILIPPINES, TAIWAN, THAILAND, AND INDIA

Milk Production

Among the countries listed in Table 6, the Philippines has the lowest local milk production for the last ten years (2014–2023) averaging only 24.30 mt. Cow's milk production represents 64% of the total production followed by buffalo (31%) and goats (5%) (USDA-FAS 2021). Despite the slight production improvements, the country still supplies only 1% of its total annual dairy requirement and the rest are imported. The low milk production is due to the small number of dairy animals in the country, which totals to 31,878 heads, including dairy cattle (9,730), dairy carabao (7,240), and dairy goats (14,908) (Ang 2017; Mojica-Sevilla 2023). Moreover, the average daily milk production is only 10 l for dairy cows, 4.5 l for buffalo, and 1.5 l for goats. Other contributing factors causing low production are poor feeding and management practices resulting to high production costs and lack of adequate infrastructure, water scarcity, poor mechanization, low productive efficiency, and high wastage due to high perishability of milk (USDA-FAS 2022; PCAARRD n.d.).

Meanwhile, the dairy industry in India is the largest globally, accounting for 24% of global milk production. The sustained and increasing production trend over the years, from 140,000 mt in 2014 to 207,000 mt in 2023, is supported by various initiatives of the government. A major contributing factor is the large inventory of bovine dairy cattle (*Bos taurus* and *Bos indicus*) and Asian domestic water buffalo (*Bubalus bubalis*), which is also the largest in the world. It was reported in 2023 that the Indian cattle herd, estimated at 307.5 million, accounts for 194.2 million head of bovine dairy cattle and 113.3 million water buffaloes. The continued herd improvement is due to the government scheme and programs focused on improved breeding, nutrition, and better animal health. However, the milk production per animal is significantly low compared to the other major dairy producers (USDA-FAS 2023). Based on the reports of DAHD Ministry of Fisheries Annual Report 2022–2023, the average milk yield per animal at the national level from different species in 2021– 2022 is as follows: exotic cows (11 kg/day), crossbred cows (8.32 kg/day), indigenous cows (4.07 kg/day), nondescript cows (2.83 kg/day), indigenous buffalo (6.62 kg/day), nondescript buffalo (4.81 kg/day), and goat (0.47 kg/day).

Like India, Taiwan's milk production is steadily increasing at 379,000 mt in 2022 to 475,000 mt in 2023 (USDA-FAS 2023). Dairy cows account for 97 percent of domestic milk production with the other 3% supplied by dairy goats.

Compared to the Philippines, Taiwan has a larger dairy animal population, with 118,408 dairy cattle across 560 farms with an average of 211 head per farm (including milking and unborn cows). Of these, 62,916 are milking cows. Taiwan also has 223 dairy goat farms, with a total

Table 6. Milk Production ('000 MT) in selected Asian countries, 2014–2023.

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	AAGR (%)
Philippines[1]	23	20	21	22	23	24	25	26	27	32	4.02
India[1]	140,500	147,000	154,000	154,000	187,700	191,000	195,000	199,000	202,000	207,100	4.58
Taiwan[1]	379	389	395	395	400	446	450	462	471	475	2.59
Thailand[2]	1,132	1,122	1,132	1,215	1,208	1,246	1,272	1,374	1,220	1,278	1.81

**AAGR – average annual growth rate*
Sources: [1]USDA-Foreign Agricultural Service
[2]Pattamanont et al. (2022) (2014-2021); FAO (2022-2023)

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of 38,543 goats with an average of 172 head per farm (including milking and unborn goats), of which 23,014 are milking goats (USDA-FAS 2021). A slight increase in dairy farms (560) was recorded in the second quarter of 2023, with 66,000 milking cows in the summer, accounting for 45% of the total cattle population (USDA-FAS 2023). These improvements are attributed to the ongoing improvements in dairy technology that resulted in an increased milk yield per head with a daily average of 19.04 kg per cow in 2020 (USDA-FAS 2021).

Similarly, Thailand's milk production grew from 1,132,000 mt in 2014 to 1,374,000 mt in 2021 before declining to 1,220,000 mt in 2022 and recovering slightly to 1,278,000 mt in 2023 (Pattamanont et al., 2022; FAO 2022–2023). This growth has been driven by improvements in farm management, genetic selection, and feed efficiency, though rising production costs and fluctuating demand contributed to past declines (Pattamanont et al. 2022). Like Taiwan, Thailand has modernized its dairy farms, achieving an average daily milk yield of 12 kg per cow as reported by the Department of Livestock Development (Pattamanont et al. 2022).

Overall, the average annual change in milk production in the Philippines, India, Taiwan, and Thailand was 4.02%, 4.58%, 2.59%, and 1.81%, respectively.

Per capita consumption of milk

The per capita consumption of milk in the Philippines is increasing throughout the years but remains to be the lowest among the countries listed below (Table 7), due to a number of factors such as low inventory of dairy animals, high human population, limited supply, low purchasing power of the average Filipino, dietary habits and poor marketing capabilities. Furthermore, the industry is far less developed. Dairy products are difficult to distribute outside of producing areas due to lack of cold storage and problems on poor infrastructure in transportation and roads. Consequently, the local dairy supply is not enough to meet the local demand and heavily depends on imports to satisfy the demand for dairy products. Thus, the country needs to improve competitiveness to lessen imports and minimize the current trade deficit (PCAARRD n.d.; Dong 2006). The Philippines obtained the highest per capita consumption of milk in 2019 and 2020 which has been consistently increasing since 2015 (Table 7). On the other hand, the per capita consumption of milk in India increased from 55 kg in 2014 to 81 kg in 2021, which is the highest compared with the Philippines, Taiwan, and Thailand. Currently, India is the largest milk-producing country and the largest consumer of dairy products since 1997 (Kalimuthu et al. 2021). It has also the highest human population around 1.4 billion (Worldometer 2024). The demand for fluid milk consumption is driven by India's

Table 7. Per capita consumption of milk (kg per year per capita), excluding butter in selected Asian countries, 2014 – 2021.

Country	2014	2015	2016	2017	2018	2019	2020	2021	AAGR (%)
Philippines	17	16	22	24	26	29	29	26	7.18
India	55	60	63	66	70	75	82	81	5.74
Taiwan	28	42	40	42	45	45	48	58	12.21
Thailand	41	32	28	29	30	29	29	30	-3.90

**This includes the milk equivalents of dairy products made from milk ingredients excluding butter. AAGR – average annual growth rate*
Source: Food and Agriculture Organization of the United Nations (2023)

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demographics where about a third of the national population is under 14 years of age and are inclined to consume higher quantities of milk. Furthermore, the increasing consumption is attributed to changing lifestyle patterns, increasing disposable incomes, and the country's increasing health consciousness. India's vegetarian consumers heavily depend on milk as a source of protein. Rural households consume almost 50% of the total milk production. The remaining 50% is sold in the domestic market of which 50% is consumed in fluid form, 35% as traditional products including cheese, yoghurt etc., and 15% consumed in the form of butter, ghee, milk powder and other processed products such as ice cream and whey powder (USDA-FAS 2022).

Domestic production accounts for 90% of the total fluid milk supply in Taiwan. However, given the difficult climate and limited agricultural land availability, Taiwan's domestic milk production cannot meet the growing demand for fresh milk. The per capita consumption of dairy products in Taiwan in 2014 was around 28 kg with a higher dairy consumption observed among children and the elderly (USDA-FAS 2014). Lee et al. (2009) reported that dairy consumption practices of school children (49.3%), adolescents (32.1%), and elderly (43.6%) were higher compared to the middle age (22.2-25.9%). The average daily dairy intake decreases with age, and the intake in the elderly is less than half a serving. The peak season for fluid milk is summer, which is the most difficult time for milk processors to satisfy demand due to the scorching heat that affects milk production.

Milk with coffee has become a fashionable beverage in Taiwan since 2008, but many coffee shops started using long-life milk instead of fresh milk due to the tight supply from domestic fresh milk and challenges in storing imported fresh milk (USDA-FAS 2014). In 2021, the per capita consumption of milk reached 58 kg and the increasing consumption is attributed to the Westernization of Taiwan's diet, health-conscious consumers, and the popularity of added-milk beverages such as Taiwan's bubble tea. Taiwan's increase in the number of convenience stores, coffee shops, and bubble tea shops has driven higher demand for fluid milk (USDA-FAS 2021). Almost 85% of raw milk is utilized for fresh milk production and the remaining is used in fermented products or flavored milk (USDA-FAS 2022).

In Thailand, per capita milk consumption ranged from 29 to 32 kg between 2015 and 2021 which is lower than the 41 kg recorded in 2014 (Table 7). The gradual increase in consumption after 2015 is largely attributed to the School Milk Program which supplies free milk to students to promote better nutrition and support the dairy industry (Canvassco 2021).

Overall, the average annual change in per capita consumption in the Philippines, India, Taiwan, and Thailand was 7.18%, 5.74%, 12.21%, and -3.90%, respectively.

Milk Importation

The importation of milk fluid in selected Asian countries from 2014 to 2023 is presented in Table 8. Milk importation consistently increased from 50,000 mt in 2014 to 118,000 mt in 2023 due to low domestic production coupled with higher demand from consumers. In 2013, the local production was at 19,640 mt against 1.866 M mt dairy requirement in 2014 (USDA-FAS 2014). The annual dairy demand was 2.5 M mt liquid milk equivalent in 2017. Major suppliers are New Zealand (39%), the United States (21%), and Australia (7%) and the country was the sixth largest market for US dairy products by value at 225 M USD (USDA-FAS 2018). Although local milk production increased by 15% in the first half of 2024, imports increased by 12.9% (NDA 2024). While the Philippines is heavily dependent on imports, India's milk production has been increasing for a decade. There were no milk imports from 2014–2023 (Table 8) because the country often imposed trade restrictive measures that effectively banned imports as a means of protecting domestic production (USDA-FAS 2023).

Taiwan also imports milk but much lower than the Philippines because their domestic production accounts for about 90% of the total fluid milk supply in 2014. However, a difficult climate, limited agricultural land availability, and emerging diseases like bovine ephemeral fever (BEF) and lumpy skin disease (LSD) limit the country from meeting the growing demand for fresh milk. In addition, a strong demand from the food service sector and the proven success of US fresh milk products from Costco caused the growth in importation. The top three suppliers of milk are Australia (27%), France (21%), and New Zealand (20%) in 2013 (USDA-FAS 2014). Due to the New Zealand—Taiwan Free Trade Agreement, domestic producers and other importers had to increase their competitiveness because New

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Table 8. Importation of milk fluid ('000 MT) in selected Asian countries, 2014–2023.

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Philippines[1]	50	45	48	50	68	105	90	110	115	118
India[1]	0	0	0	0	0	0	0	0	0	0
Taiwan[1]	22	25	28	55	60	74	79	58	52	60
Thailand[2]	922	1,110	950	1,000	1,100	1,000	1,050	1,120	1,207	Nd

Sources: [1]USDA-Foreign Agricultural Service
[2]Food and Agriculture Organization of the United Nations

Zealand dairy products are able to enter Taiwan without tariff or quota restrictions in 2025 (USDA-FAS 2018). Milk imports decreased by 17% in 2021 which pushed the local producers to exceed production to meet the high demand. The demand for fluid milk continues to increase due to food and beverage trends and changing consumer preferences (USDA-FAS 2022).

The fluid milk importation of Thailand increased from 922,274 mt in 2014 to 1,207,703 mt in 2022, reflecting a 31.5% rise (FAO 2022). The domestic raw milk supply is insufficient to meet demand, with nearly all of it being allocated to the production of liquid milk for ready-to-drink products and school milk programs (Dairy Global 2023).

Overall, the average annual change in milk importation in the Philippines, Taiwan, and Thailand was 11.8%, 15.5%, and 3.9%, respectively, while it remained at 0% for India.

Key Players of the Dairy Industry

In the Philippines, the dairy industry is characterized by the dominance of smallholders, which constitute 99.2% of the 10,563 dairy cattle farmers. Despite challenges such as low productivity, high production costs, and limited access to markets and veterinary services, smallholders are crucial for sustaining local milk production, reducing dependency on imports, and supporting rural livelihoods. Key players include cooperatives like BADACO and federations such as KKMI, which help smallholders by aggregating milk supply, facilitating processing, and improving market access. Commercial farms and institutional herds managed by the PCC, play a significant role in producing high-quality local dairy animals and maintaining genetic diversity (DA-NDA 2022).

Likewise, India's dairy industry is predominantly driven by smallholders, which contribute 70-80% of the total milk production. About 95% of smallholder dairy farmers rear 1 to 5 milking animals, generating income and employment for approximately 80 M rural households (Lal et al. 2022). Cooperatives like Amul and Nandini (Karnataka Milk Federation) are critical in integrating smallholders, providing procurement, processing, and marketing support (Nanda Kumar et al. 2022). Private companies such as Mother Dairy, Nestle India, and Hatsun Agro Product also enhance market access and offer essential services. Commercial dairy farming in India is growing, particularly in urban and peri-urban areas, with larger farms typically starting with 20 high-producing animals. The Indian Council of Agricultural Research (ICAR) and the National Dairy Research Institute (NDRI) provide crucial support, focusing on improving breeds, feed quality, and farm management practices. The National Dairy Development Board (NDDB) implements policies and programs that have significantly increased milk production and smallholder participation (IMARC Group 2024).

Taiwan's dairy industry is primarily composed of family-owned farms, with an average herd size of 150-200 heads per farm. These farms are essential for maintaining a steady production of fresh milk, which is the primary dairy product in Taiwan. Farmers typically operate under long-term contracts with major dairy processors, ensuring market stability. Despite challenges

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such as labor shortages, rising production costs, and strict environmental regulations, these farms benefit from substantial government support through the Ministry of Agriculture (MOA) (Chen 2023). Cooperatives and private sector partnerships play a vital role in aggregating milk supplies, facilitating processing, and improving market access. Larger dairy operations in Taiwan utilize advanced management practices and technologies to enhance productivity, significantly contributing to the production of processed dairy products.

Thailand's dairy industry includes both smallholder and commercial farms, with smaller farms generally being more cost efficient than larger ones (Lapar et al. 2005). For optimal efficiency, it is recommended that 70-75% of the herd should consist of milking cows (Lapar et al. 2005). The Department of Livestock Development (DLD) and the Dairy Farming Promotion Organization of Thailand (DPO) support the sector through training, veterinary services, and infrastructure. Larger commercial farms manage hundreds to thousands of cows, benefiting from economies of scale and better market access. Major companies in Thailand's dairy market, such as CP Group, Tipco Foods, Dutch Mill Group Public Company Limited (DMG), Thailand President Foods PCL, Betagro PCL, and FrieslandCampina PLC, are focusing on expanding production capacities and innovating products to meet changing consumer preferences (6Wresearch 2023).

The dairy industries in the Philippines, India, Taiwan, and Thailand share several similarities while exhibiting distinct differences in their structure and dynamics. All four countries heavily rely on smallholder farmers and cooperatives to drive their dairy sectors. In the Philippines, the industry is dominated by smallholders. Similarly, India's dairy industry is predominantly smallholder-driven, with cooperatives like Amul and Nandini playing significant roles in providing comprehensive support. In Taiwan, family-owned farms with larger herd sizes are essential for maintaining fresh milk production, supported by long-term contracts with processors and government assistance (USDA FAS 2023). Thailand's dairy industry features a blend of smallholder and commercial farms, with support from cooperatives and government bodies addressing high production costs and volatile milk prices (Chungsiriwat and Panapol 2009).

Cooperatives in all four countries are vital for integrating smallholders into the dairy value chain, providing market access, and ensuring stable incomes. Government bodies and research institutions offer substantial support through policies, training, and technical assistance, addressing common challenges such as low productivity and high production costs. The differences lie in herd sizes and farm scales. The Philippine smallholders typically manage fewer than five cows and caracows, along with no more than 35 does (PSA 2023), whereas Taiwanese family farms are much larger. In contrast, Indian commercial farms typically start with 20 high-producing animals and scale up as resources allow, while Thai commercial farms manage significantly larger herds, benefiting from well-developed infrastructure and government support. Additionally, Taiwan's market stability is supported by long-term contracts with processors, unlike the more variable market conditions faced by Philippine and Thai smallholders. India's dairy industry also stands out for its significant economic impact, generating income and employment for around 80 million rural households. These variations in structure, market integration, and economic impact shape the distinct characteristics of the dairy industries in these countries, influencing their success and sustainability (IMARC Group 2024).

Innovations and Technologies

This section discusses the innovations and technologies in the dairy industry in different stages of adoption and practice in the Philippines, India, Thailand, and Taiwan (Table 9).

Production Practices and Technologies

Breeding and reproductive improvement technologies. The Philippines, India, Taiwan, and Thailand have practiced genetic selection for their dairy animals. However, the extent of use may vary. Genetic selection in the Philippines is limited to dairy buffalo and focuses on evaluating superior animals for milk and milk component traits and breeding stock selection (Herrera et al. 2021). The breeding program of PCC started in 1992 during the United Nations Development Program/ Food and Agriculture Organization (UNDP/FAO)-assisted project, titled "Strengthening of the Philippine Carabao Research and Development Center (PCRDC)," and continued during the institutionalization of the PCC. A genetic improvement program was further pursued including the recording of pedigree and phenotype, creation of a pedigree and performance database,

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genetic evaluation and progeny testing, cryobanking of frozen semen, and continuous backcrossing which resulted in the creation of "full-blood" and "purebred" dairy buffaloes ("Pinoy buffalo") (Flores 2023). On the other hand, NDA implements the dairy herd build up program which aims to ensure and accelerate the increase in both local dairy stocks and local milk production through various program strategies such as animal importation, upgrading of existing local animals to dairy breed, production of replacement stocks through dairy breeding programs like artificial insemination programs and stock farm establishment, and the preservation of existing stocks.

The use of fixed-time artificial insemination is becoming popular in the Philippines to improve fertility and pregnancy rates in beef and dairy animals (Serrano 2024). Meanwhile, India, Taiwan, and Thailand use genetic selection to improve milk yield and fat content in its dairy animals.

In the Philippines, 71,273 AI procedures were performed in 2013 by 932 AI technicians from local government units, NDA, and PCC (Fernando and Duran 2017). By 2023, the number of AI services increased to 95,081, carried out by 1,116 trained AI technicians (BAI 2024). The generally low success rate of AI based on calf drop affected the herd build up program of the Philippines. From 2014 to 2023, the average calf drop was 24.9% for dairy cattle and 21.1% for buffaloes (BAI 2024). In general, AI services in the Philippines and in the Asian Region are limited by the inadequate and expensive supply of liquid nitrogen or LN2 (Joint FAO 2005). In 2006, LN2 mother tanks used for storing semen were distributed to local government units in the Philippines as a support for an expanded AI program (Pablico and Diloy 2007).

In India, Taiwan, and Thailand, AI enables the efficient use of semen from superior bulls, leading to increased milk production and reduced risk of diseases (Rathod et al. 2017; Nigatu 2018). In India, for example, initiatives were developed to promote sex-sorted semen technology which include establishment of 11 sexed semen laboratories and offering the technology to farmers at subsidized rates (Singh et al. 2009; Tiwari et al. 2022). Meanwhile, sex-sorted semen technology in Taiwan is used for efficient heifer production (Chang et al. 2017) while Thailand had some studies on alternative methods for sexing (Thongkham et al. 2021) and sex ratio determination (Khamlor et al. 2014). An earlier report by Fernando and Duran (2017) cited that the use of sexed semen technology through the PCC in the Philippines was at the planning stage.

Of the four countries, Taiwan is leading the utilization of genetic selection, AI, and sex-sorted semen. India comes next, followed by Thailand, while the Philippines remains in the early stages of adopting breeding technologies. The prevalence of smallholder farmers in the Philippine dairy industry, combined with limited resources, likely restricts the adoption of breeding innovations. Palacpac et al. (2016) found that education, dairying experience, animal inventory, and access to technical assistance influence the adoption of innovations. Building on this, Reproto et al. (2024) examined dairy farmers' adoption of PCC-endorsed feed technologies using the Theory of Reasoned Action (TRA). Land ownership and herd size encouraged concentrate feeding while other socioeconomic factors had little impact. Despite farmers' positive attitudes toward feeding innovations, practical challenges hindered adoption, while guidance from extension staff and peer farmers played a key role in shaping their decisions.

Feeding Systems. All four countries are keen on improving feeding practices to boost dairy production. In Taiwan, the Total Mixed Ration (TMR) method, where all feed ingredients are mixed and delivered to the animals, is widely practiced in most farms (Wu et al. 2019). Labor shortages and increasing herd sizes resulted in automated feeding processes in Taiwan. Likewise, TMR is also commonly practiced in India (CGIAR 2021), though information on the use of automatic feeding systems (AFS) is limited. In Thailand, dairy cooperatives sell a total mixed ration to smallholder farmers for dairy cattle (Tiemann 2023). Although AFS in Thailand is not widely documented, the country's smart farming initiatives involving automation suggest that the adoption of AFS may be currently confined to large commercial farms or is still in its early stages. In the Philippines, the use of TMR is limited to a few commercial farms while the AFS technology has not yet been adopted by the country's dairy industry.

Milking technologies. Taiwan is leading the adoption of milking technologies as the country incorporates robotic milking systems into their dairy farms since 2017, with government support promoting wider adoption (Wu et al. 2019). According to Aiumlamai et

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al. (2012), more than 90% of Thailand's dairy farms use bucked type milking machines, and the pipeline milking system is becoming more popular. However, no farms use an automatic milking system. On the other hand, Thailand's smart farming initiatives include automated milking systems. Although information on the use of robotic milking in both Thailand and India is limited, strong government support in both countries suggests that adoption of this technology is possible. A survey of 30 Indian dairy farms revealed that the top three factors encouraging the possible adoption of automation in dairy operations are time savings, reduced drudgery, and maintained milk quality (Meena et al. 2022). The same study also indicated that the high initial investment cost and insufficient government subsidies were possible reasons for non-adoption.

Automated or robotic milking systems have not been adopted in the Philippines. The significant investment required for robotic milking systems might hinder adoption by resource-limited smallholder dairy farmers, which dominate the dairy industries in India, Thailand, and the Philippines.

Animal Health and Welfare

Health monitoring. Of the four countries, Taiwan is the most advanced in the utilization of existing smart management systems incorporating health monitoring softwares and devices. Taiwan focuses on heat stress monitoring. In India, reports indicate the use of health monitoring systems in dairy cows (Dineva and Atanasova 2023) although there is no report on the extent of adoption. Rathod and Dixit (2020) reported that while several precision dairy farming technologies are available to monitor physiological, behavioral and production indicators, their adoption in India is still in its infancy. In Thailand, smart sensors enhanced both the cattle reproductive success and the farmers' satisfaction (Kaewbang et al. 2024). The Philippines, however, may be in the early stages of exploring the smart sensor technology for health monitoring of dairy animals.

Welfare practices. In terms of animal welfare, Taiwan aligns its dairy industry with global trends through policy, better housing design, and openness to new technologies. Taiwan has established voluntary guidelines for dairy cattle welfare indicating requirements for space, bedding, access to outdoors, and milking parlor design to promote animal welfare (Dijk 2021). Despite having the largest number of dairy cattle, India showed little work to assess animal welfare (Mullan et al 2020). However, India is taking initial steps to incorporate emerging technologies for dairy cow welfare. Earlier studies focused on addressing limitations of traditional systems and exploring solutions for lameness, health monitoring, and heat stress. In India, it has been recommended that animal welfare issues and problems in traditional smallholder and commercial dairy farming be studied separately since these systems employ different farming practices and technologies (Kumar et al. 2017).

On the other hand, Thailand has shown signs of progress in animal welfare with its guidelines on animal welfare established by the Department of Livestock Development (MFA - Thailand 2020). The Philippines is still in the early stages of adopting new technologies for dairy animal welfare. Some commercial farms have improved housing facilities with automatic sprinkler, cow brush, improved beddings, fans, and other amenities to ensure the comfort of the animals.

Table 9 summarizes the degrees of adoption of various dairy-related technologies and innovation by the Philippines, India, Thailand, and Taiwan.

Product Quality and Safety

Processing technologies. Various dairy processing technologies such as pasteurization including Ultra-High Temperature (UHT) and High-Temperature, Short-Time (HTST) pasteurization, and homogenization are practiced across four countries. However, due to the lack of reliable cold chain systems and limited production in the Philippines, a significant amount of imported milk powder is reconstituted into UHT milk. This approach not only addresses the need for milk processing despite infrastructural challenges but also points to a reliance that could potentially affect the local dairy industry (USDA-FAS 2020). In contrast, in India, milk processing methods include pasteurizing, boiling, and sterilizing. Nevertheless, some localities still consume raw milk, which poses health risks, highlighting the need for a greater widespread adoption of safe milk processing techniques (Dairy Knowledge Portal n.d.). Meanwhile, in Taiwan, most milk undergoes UHT pasteurization, ensuring long shelf life and safety. Similarly, this method is also widely practiced in Thailand. Pasteurized and UHT milk is provided for milk feeding programs and exports.

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Table 9. Summary of adoption of dairy-related technologies, practices, and innovations by the Philippines, India, Taiwan, and Thailand.

Technologies/ Innovations	Philippines	India	Taiwan	Thailand	References
Breeding					
Genetic selection	practiced	practiced	practiced	practiced	Herrera et al. (2021); Fernando and Duran (2017); Rathod et al. (2017); Nigatu (2018); Singh et al. (2009); Tiwari et al. (2022); Chang et al. (2017); Thongkham et al. (2021).
Artificial insemination	practiced	practiced	practiced	practiced	
Sex-sorted semen	Not yet adopted	adopted	practiced	adopted	
Feeding Systems					
Total mixed rations	limited adoption	practiced	practiced	adopted	CGIAR (2021); Wu et al. (2019); Tiemann (2023).
Automatic feeding system	Not yet adopted	adopted	practiced	adopted	
Milking Technologies					
Milking machines	practiced	practiced	-	practiced	Aiumlamai et al. (2012); Meena et al. (2022); Wu et al. (2019).
Automatic/ robotic	Not yet adopted	adopted	practiced	Not yet adopted	
Health and Welfare					
Monitoring devices	Not yet adopted	adopted	practiced	adopted	Dineva and Atanasova (2023); Kaewbang et al. (2024); Mullan et al. (2020); Dijk (2021); MFA - Thailand (2020).
Welfare practices	adopted	adopted	practiced	Not yet adopted	
Product Quality and Safety					
Processing	practiced	practiced	practiced	practiced	Kumar (2019); Cabugwas (2024); DTI (n.d.); Suman (n.d.); USDA-FAS (2018); Taiwan News (2023); Foremost Thailand (n.d.); DTI (2023); Talavera (2021); Rangaprasad (2022); NIPS (n.d.); HOPAK (n.d.); Packaging Gateway (2021)
Quality control	adopted	adopted	practiced	adopted	
Market Adaptation and Consumer Preferences					
Product development	practiced	practiced	practiced	practiced	Global Parachem (2023); USDA-FAS (2020); Dairy Knowledge Portal (n.d.); Pattamanont et al. (2022); Amadora (2024); Kumar (2019); Malik et al. (2023); Yadav, et al. (2022); Liu (2019); USDA-FAS (2021)
Packaging technologies	practiced	practiced	practiced	practiced	

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Technologies/ Innovations	Philippines	India	Taiwan	Thailand	References
Technology Integration and Infrastructure					
Digital transformation	adopted	practiced	practiced	adopted	PNA (2022); Neo (2022); Narendra Modi (2024); National Dairy Development Board (2021); Dharmaraj (2023); Department of Animal Husbandry and Dairying (n.d.); Sindakis and Showkat (2024)
Infrastructure development	adopted	practiced	-	adopted	

This dual approach supports both domestic consumption and international trade (Pattamanont et al. 2022).

Overall, the diverse processing methods in India can result in health hazards from raw milk intake, emphasizing the need for proper consumer education. On the other hand, advanced dairy processing technologies in Taiwan and Thailand guarantee milk safety and long shelf-life, supporting both domestic demand and export markets. Their strategies reflect mature dairy sectors capable of sustaining quality standards while expanding through global commerce.

Quality control. Each country exhibits different stages and approaches to adopting quality control technologies in the dairy industry, which reflect their unique challenges and strategic goals. For instance, the Philippines and India are just beginning to adopt quality control technologies, whereas Taiwan and Thailand have reached more advanced stages in their implementation. In the Philippines, maintaining the quality of fresh milk is challenging due to inadequate processing and distribution systems, as well as cold chain issues. To address these challenges, Metro Pacific Investments Corp. (MPIC), through Metro Pacific Agro Ventures, Inc. (MPAV), has partnered with Carmen's Best group. This partnership aims to digitalize the dairy industry by integrating cloud-based systems in order to improve milk supply and enhance the quality of life of dairy cows. Moreover, Carmen's Best collaborates with Cloud 4C to streamline supply chain operations, ensure product traceability, and optimize distribution channels (Amadora 2024).

Similarly, in India, only 62.3% of milk sold meets standards, which is below the global average (Kumar 2019). The primary issues include milk adulteration, contamination, fraud, and improper handling, underscoring the need for effective traceability systems (Malik et al. 2023). Although emerging techniques for detecting milk adulteration and contamination exist, they are often complex, expensive, and lab-based, which limits their widespread application (Yadav et al. 2022).

In Thailand, the Department of Livestock Development is primarily responsible for ensuring milk quality control. Although quality control technologies and innovations are not yet widely practiced, ongoing R&D are moving towards this. Ensuring high-quality milk is a strategic goal of the Thai government as it boosts national consumption. Furthermore, high-quality milk can serve as an export product or a raw material for other export goods (Pattamanont et al. 2022). In contrast, Taiwan enforces strict government regulations to control the quality of dairy products, including a traceability system known as the Traceability/Good Agricultural Product (TAP) system (Liu 2019). Additionally, the quality of raw milk is meticulously graded based on the Somatic Cell Count, a critical indicator of milk hygiene and dairy cow health (USDA FAS 2021). The government's commitment to ensuring high-quality milk is further supported by the Smart Agriculture 4.0 Program, which utilizes advanced technologies to enhance dairy farming practices, improve milk quality, and ensure sustainability.

Market Adaptation and Consumer Preferences

Product development. Product development and innovation in the dairy industry are progressing in four countries through the support of government agencies and private partnerships.

In the Philippines, NDA, PCC,, Department of Trade

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and Industry (DTI), and DOST-PCAARRD collaborate to advance dairy production by focusing on research, extension services, business development, funding support, and the adoption of innovative technologies. For example, the agency offers food safety training and technological interventions for sustainable dairy practices, which include basic handling, food safety, and good manufacturing practices. Furthermore, it assists and guides cooperatives in developing GMP-compliant plant layouts and organizational structures (Cabugwas 2024). Additionally, the DTI supports farmers through similar programs and provides Shared Service Facilities (SSF) in order to improve storage and packaging, thus helping farmers diversify their processed products, including dairy (DTI n.d.). Meanwhile, in India, rising health consciousness and urbanization are driving dairy product development. The industry responds to diverse dietary needs by offering traditional products like curd, ghee, paneer, and khoa, as well as modern value-added dairy products such as cheese, yogurt, whey, and ice cream (Suman n.d.).

On the other hand, Taiwanese producers focus on new product formulations and combining dairy products to create enhanced beverages (USDA-FAS 2018). Moreover, research into plant-based milk is also underway to meet the growing demand for alternatives (Taiwan News 2023). Similarly, in Thailand, innovation comes through academic and private partnerships. Programs like the Thai Dairy Farmers' Capacity Development Program, which is supported by Royal FrieslandCampina, help farmers adopt best practices from Dutch dairy farming in order to improve milk quality and farm management (Foremost Thailand n.d.).

Packaging technologies. Various packaging technologies are being utilized across the four countries, which showcase innovation and efficiency. In the Philippines, advanced technologies include bottle blow molding machines, smart packaging, and methods to extend the shelf life of carabao milk. For example, DTI introduced bottle blow molding machines through the SSF on dairy processing, thereby improving efficiency and reducing reliance on third-party packaging (DTI 2023). Additionally, smart packaging incorporates features such as prizes via QR codes and collects consumer data to further optimize marketing strategies (AIPIA 2024). Furthermore, San Miguel Corporation (SMC) developed a packaging technology that extends carabao milk's shelf life by six months, which can significantly enhance product marketability (Talavera 2021).

Similarly, in India, milk packaging has evolved from traditional plastic pouches and glass bottles to modern, eco-friendly options to improve the freshness and safety of dairy products (Rangaprasad 2022). Innovations include the Filpack Series from Nichrome, which packs 12,000 pouches per hour, along with modern materials like Tetra Pak, PET bottles, and biodegradable options (NIPS n.d.).

In Taiwan, the Smart Agriculture 4.0 Program supports the use of a fermented milk packaging machine with a vertical sealing mechanism, in addition to other modern methods like shrink labels and flexible packaging for dairy products (HOPAK n.d.). Likewise, in Thailand, sustainable packaging solutions are being developed and used by FrieslandCampina Thailand. These innovative cartons provide nutritious drinks in a convenient and eco-friendly format (Packaging Gateway 2021).

Technology Integration and Infrastructure

Digital transformation. The Philippines and Thailand are in the initial stages of digital transformation, particularly, in their agricultural sectors. In the Philippines, through a partnership with Israel, the government aims to enhance its local dairy industry by implementing digital transformation and smart farming techniques (PNA 2022). This initiative marks the country's gradual contribution to the Fourth Industrial Revolution. Conversely, Thailand has committed to accelerating its digital transformation plans in the agriculture industry by utilizing big data, smart agriculture, e-commerce, and agribusiness improvement (Neo 2022).

Taiwan and India have more advanced technological capabilities. For instance, in India, the e-GOPALA mobile application has been successfully adopted (Narendra Modi 2024). This application helps farmers buy and sell disease-free germplasm, access quality breeding services, and provide proper nutrition and ethno-veterinary medicine for their animals (National Dairy Development Board 2021). Additionally, another mobile application, Dugdh Sanakalan Sathi (Milk Collection Partner), offers comprehensive services to milk producers (Dharmaraj 2023). Meanwhile, Taiwan, through its Livestock Research Institute, has developed a remote application that serves as maintenance guidance for dairy farm machinery and equipment,

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which allows farmers to consult experts on cattle care. This development underscores Taiwan's commitment to integrating advanced technology into its agricultural practices.

Smart and precision infrastructure development. The Philippines and Thailand are in the early stages of developing smart and precision infrastructure to support their dairy industries. In the Philippines, a partnership with Israel will introduce smart and precision agriculture, thereby adapting Israeli technology to local conditions. This smart farming initiative will incorporate the Internet of Things (IoT), cloud computing, robotics, and artificial intelligence, which will significantly optimize dairy animal performance and enhance decision-making systems (PNA 2022).

On the other hand, India has established the Dairy Processing and Infrastructure Development Fund, which aims to modernize milk processing plants and machinery while expanding infrastructure for processing more milk. This expansion includes the development of cattle feed plants, milk transportation systems, and marketing infrastructure, such as e-market systems and bulk vending systems (Department of Animal Husbandry and Dairying n.d.). Additionally, cold storage facilities and ICT infrastructure, including blockchain technology and the Information Network for Animal Productivity and Health (INAPH), are being implemented. Specifically, INAPH can store individual records of all vaccinations and other medical interventions performed on each animal by capturing its unique ear tag number, thus providing real-time vaccination data accessible online (National Dairy Development Board 2013). Moreover, to address the challenges of infrastructure and connectivity, India has launched a collaborative community outreach initiative to bring technology to remote areas like Bharat. One of the flagship initiatives of the Indian government is BharatNet, which aims to connect the remotest parts of India with high-speed broadband internet under its Digital India Program (Sindakis and Showkat 2024). However, there is limited information available on specific infrastructure developments in Taiwan.

Program and Policies

Milk feeding program

The Philippines, India, and Thailand have wide-ranging milk feeding programs that have focused on improving children's nutrition. The milk feeding program in the Philippines was initially introduced by NDA in 1995 in partnership with other government agencies (Dela Torre 2022). The Philippines implements a Milk Feeding Program to address malnutrition among school children. In 2023, through RA 11037, approximately 3.48 million liters of milk were distributed to 651,769 children through the milk feeding programs of the DSWD and DepEd. Additionally, 38 processors assisted by the NDA served as suppliers for the Milk Feeding Program (NDA 2023). In 2022, the PCC assisted the dairy cooperatives/ suppliers to supply the milk requirements of 1,330,984 children from Kindergarten to Grade Six enrolled in public elementary schools under the DepEd, 413,360 undernourished children under the supplementary feeding program of the DSWD) (PCC 2023).

In India, milk is an integral part of the Mid-Day Meal Scheme to improve nutrient consumption. India's Mid-Day Meal was commenced in 1995 by the central government (IFMR 2010). The Thailand School Milk Program began in 1985 in response to farmers' protest over unsold milk (Suwanabol n.d.). The program distributes milk to school children nationwide to elevate their nutritional standards. Compared to the Philippines, India's and Thailand's milk feeding programs are more structured and widespread. Taiwan does not have milk feeding programs due various factors such as economic considerations and cultural preferences, among others.

Genetic improvement programs

In the Philippines, the NDA focuses on the Dairy Herd Improvement Program that aims to enhance genetic quality of local dairy stocks and increase milk production using proper breeding practices, artificial insemination, establishment of multiplier farms and preservation of existing stocks (NDA n.d.). Meanwhile, the PCC implements the Genetic Improvement Program (GIP) to enhance the genetic potential of native carabaos for milk, meat, draft, and hide. Through direct backcrossing of 50:50 crossbreds with purebred genetics to achieve a 75:25 blood composition, milk production can be significantly improved. This program aims to develop carabao-based enterprises to increase the income and nutritional well-being of farming communities (PCC 2022).

Likewise, Taiwan's Livestock Research Institute invests in genetic improvement programs highlighting innovative breeding approaches through the use

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of genomic selection and advanced reproductive technologies as part of its smart agriculture 4.0 programs (Wu et al. 2019). In India, the National Dairy Development Board (NDDB) leads large-scale breeding enhancement programs that crossbreed high quality foreign breeds with indigenous cattle (NDDB 2017). Similarly, Thailand also has successful initiatives on the genetic improvement of its dairy animals, such as the development of the Thai Milking Zebu (75% Holstein-Friesian blood; 25% other breeds) and Thai Friesian cattle (>87.5% Holstein-Friesian blood) which are adapted to the tropical climate and have improved milk production (Chungsiriwat and Panapol 2009).

Feed Resources Programs

Thailand and India have developed programs that primarily focus on utilizing local feed resources in order to improve sustainability and minimize costs. India's TMR system blends locally sourced ingredients to provide balanced ration to the dairy animals which can benefit smallholders (NDDB 2017). Similarly, Thailand also integrates local agricultural by-products into its feedstuff resources (Wanapat et al. 2018), making the system accessible to small-scale farmers. Taiwan's Smart Agriculture 4.0 program offers precision farming to dairy farms which is becoming an essential to dairy herd management. This program includes automatic systems to feed a TMR to improve efficiency, productivity and management in dairy farming (Wu et.al. 2019). On the other hand, the Philippines still faces challenges with feed resources due to its archipelagic geography.

Government Policies

In the Philippines, the NDA leads the development of the Philippine dairy industry through its mission to provide well-crafted policy, science-based technical expertise, sound business support, and effective management of dairy programs. This government-owned and controlled corporation that was created through the RA 7884 or the National Dairy Development Act of 1995 assumes control and supervision on all of the dairy-related government agency personnel and programs which includes, but are not limited to, milk prices, market assistance for dairy farmers, collaborations with other organizations and cooperatives, and so much more. Moreover, under RA 10611, also known as the Food Safety Act of 2013, the NDA is designated as the food safety regulatory agency responsible for ensuring the safety of milk production and post-harvest handling. In addition, RA 11037 or the "*Masustansyang Pagkain Para sa Batang Pilipino Act*'' aims to address the undernutrition of the Filipino children by promoting the livelihood of smallholder, local dairy farmers. To complement the NDA's program on the development of the Philippine dairy industry, the PCC focuses on enhancing buffalo species and providing targeted assistance to boost dairy farmer productivity and livelihoods. Mandated to conserve, propagate, and promote carabaos as sources of draft power, meat, milk, and hide, the PCC implements the Carabao Development Program. This program encompasses the GIP, Carabao-based Enterprise Development initiatives, and Research for Development efforts.

The Department of Animal Husbandry and Dairying (DAHD) in India, the Government's Milk Board of Thailand, and the Tariff Rate Quota (TRQ) and Special Safeguard (SSG) in Taiwan are the main governing bodies of the said countries for their dairy industries. The DAHD in India aims to be responsible for livestock production, preservation, and protection of other diseases to enhance productivity by providing assistance and advice for the state government regarding the animal husbandry and dairy development. This also encompasses infrastructure development for the improvement of value chains and superior germplasm at livestock rearing. The DAHD also helps in maintaining good quality milk products by overseeing the "Delhi Milk Scheme" which provides milk to the consumers of the national capital region.

Both Taiwan and Thailand have implemented government policies to regulate their dairy industries and ensure stable milk supplies. In Taiwan, the government has introduced regulations and trade mechanisms like the TRQ and special agricultural safeguards (SSGs) to control the import of dairy products. The SSG is essentially an import duty imposed to address sudden surges in imports (WTO 2008), while the TRQ is a system that combines import quotas and tariffs to regulate the flow of specific dairy products (WTO 2004). These measures help balance domestic production with imports and protect domestic producers from import surges. Similarly, in Thailand, the Government's Milk Board plays a crucial role in setting milk price policies, administering school milk programs, and managing imported milk powder. These interventions aim to stabilize milk prices, ensure adequate supply, and

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promote milk consumption.

In comparing the four government policies in said countries, all of these aim to regulate, assist, and ensure the efficiency and success of the dairy industry of the locality by overseeing the imports, prices, quality, quantity, access, and assistance to the dairy farmers and consumers concerning milk and other dairy goods. The NDA of the Philippines and DAHD of India are governing corporations which oversee the same matters. However for Thailand and Taiwan, both countries highlighted only specific policies that focus on the control of imports, quantity, and prices of milk and milk products.

Moreover, due to varying consumer needs and financial circumstances, the Philippines places significant emphasis on providing assistance to undernourished children, with 28.8% of children affected (Global Nutrition Report 2022). Additionally, a persistent challenge for the Philippine dairy industry is the limited access that dairy farmers in rural areas have to urban markets, hindering greater efficiency and growth.

IV. RECOMMENDED KEY STRATEGIES FOR THE PHILIPPINE DAIRY INDUSTRY

Strengthening the Philippine dairy industry, which currently meets only 1% of the country's demand, requires closing the technology gap, improving breeding and management practices, enhancing feed resources, and ensuring product safety and quality. Dairy farmers play a crucial role in these efforts. The Philippines can adopt proven technologies and policies from other countries, particularly those tailored for small- and medium-scale farms. For example, stakeholders can implement Thailand's dairy breeding initiatives, such as Thai Milking Zebu cattle (75% Holstein-Friesian blood; 25% other breeds) and Thai Friesian (>87.5% Holstein-Friesian blood) breeds. Similarly, India's reproductive technologies including the Dairy Herd Improvement Programme Actions (DIPA), sexed semen technology, and embryo transfer technology (ET) deliver proven results. Integrating Taiwan's Smart Agriculture 4.0 solutions, such as Total Mixed Ration diets, and Thailand's innovative use of locally available feed resources, can further enhance adaptability and efficiency.

The government and private sector must modernize milk collection, transportation, and distribution systems while adopting digital and smart farming technologies. With adequate support, dairy cooperatives can develop value-added products, conduct training programs, and address knowledge gaps. However, these initiatives will require significant investment in infrastructure from both the government and private sectors.

Stakeholders must ensure equitable assistance, particularly for local cooperatives. These cooperatives, already producing internationally compliant milk and products, are well-positioned to spearhead initiatives with proper support. They can drive value-added product development, such as cheese and ice cream, and address industry skill gaps through training programs and community outreach. This empowers cooperatives to enhance the sector's competitiveness by addressing manpower and skill deficiencies.

Key strategies include:

- Enhancing breeding programs using indigenous animals, sexed semen, and reproductive technologies such as AI and Fixed Time AI programs;
- Optimizing feed resources with Total Mixed Ration diets and locally available feedstuff;
- Modernizing production through digitalization, smart technologies, and efficient post-production logistics;
- Improving management practices including cow comfort, animal health and welfare; and
- Expanding training, capacity building, and cooperative-led initiatives to promote technology adoption.

It is recommended that stakeholders review financial support systems to eliminate barriers and effectively address farmers' needs. Coordinated efforts and long-term investments are essential to adopting these technologies and policies. The government should institutionalize dairy improvement programs under the Department of Agriculture to focus on genetic improvement, nutrition, herd management, post-production practices, and stakeholder collaboration to ensure sustainable growth in the local dairy sector.

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IV. SUMMARY AND CONCLUSION

The Philippine dairy industry is characterized by smallhold farms and a reliance on imported milk. The country has experienced gradual growth in local milk production by an average of 4.15% each year from 2015 to 2023 but remains insufficient to meet the country's demand over the years. While the number of dairy cattle has declined, programs from various government agencies, such as the NDA and PCC, have contributed to boost the local dairy production. Despite these efforts, smallholder producers and cooperatives face major challenges such as limited funding, low private sector investment, and logistical issues, which hinder growth and keep the industry dependent on imports. Nevertheless, the expanding middle class and growing population present opportunities to drive demand.

Compared to countries like Thailand, Taiwan, and India, the Philippines falls behind milk yield, self-sufficiency, and production efficiency, relying heavily on imports to meet the local demand. Contributing factors include insufficient government support across various programs, infrastructure deficits, and limited adoption of modern technologies. Lessons from these countries—advanced breeding programs, policy reforms, and infrastructure modernization—offer valuable insights for local adaptation. Addressing issues like financing, infrastructure, cooperative-led milk collection, and high-quality production is critical for progress. Success depends on evaluating strategies suited to local conditions and coordinating efforts among all stakeholders. Technological advancements and sustainable practices, supported by research institutions are also essential for boosting productivity.

By addressing these critical areas such as breeding and reproduction, nutrition, capacity building, and digitalization, the Philippines can enhance its dairy production, improve the livelihoods of local farmers, address malnutrition, and reduce dependence on imports. Harmonization of programs and collaboration among government agencies including NDA, PCC, BAI, LGUs, alongside research institutions, private sector, and other stakeholders is key to achieving sustainable growth in the dairy industry.

Contributions of Authors:

All authors made substantial intellectual contribution to this paper. All authors were involved in the review and revision of the manuscript.

- AN DelBarrio and KB Turaja developed the central theme of the review article and provided comprehensive reviews and comments on the entire manuscript, offering guidance for improvements.
- KB Turaja and MAT Maghirang provided insights into the evolution of the Philippine Dairy Industry and compiled relevant government laws and policies affecting the sector.
- LJ Guillermo and BT Salazar conducted an analysis of milk production, consumption trends, and the population of dairy animals in the Philippines.
- KCB Tenorio identified and discussed the key players in the dairy industry as well as the Strengths, Weaknesses, Opportunities, and Threats (SWOT) associated with the Philippine dairy industry.
- KB Turaja analyzed the milk production, per capita consumption of milk, and milk importation across the selected countries.
- BT Salazar and MAT Maghirang reviewed and compared innovations and technologies across selected countries.
- MAT Maghirang assessed relevant programs and policies on the dairy industry across the selected countries.
- KB Turaja and MAT Maghirang ensured that the review article adhered to the prescribed formatting guidelines.
- KB Turaja, MAT Maghirang, KCB Tenorio, BT Salazar, and LJ Guillermo collaborated to verify the completeness and accuracy of references cited in the review article.

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