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Redesigning the Global Dairy Industry in Climate Change Era, for Sustainable Food Production and Livelihood: Some Futuristic Outlooks

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Abstract: In recent years, global warming associated unprecedented climate change like, sustained higher temperatures, humidity, heat waves and solar flares have led to economic losses in $ billions to dairy sector, globally. When exposed to heat stress or other adverse conditions, livestock respond by different thermoregulatory mechanisms, resulting into significant production losses. While, most of the studies explored heat stress impact on dairy sector in a specific region or one continent, the impact of global warming and its interactions with other variables transiting dairying are yet to be clearly comprehended. So, in this review we explore some key drivers which influence dairying and also the future adaptations for the sector for sustained production. It can be comprehended that, in future not only the dairy breeds will have to evolve, but also the intensive production systems, fodder production and processing units. Additionally, with traditional products value addition will be essential, further assessment of environmental impact and, flexible national and international trading and government laws and policies must be implemented to make the dairy sector more sustainable, under the global warming scenario.

Keywords: Climate change, Global warming, Milk Production, Key drivers, Sustainable dairy.

Introduction

The United Nations (U.N.) has predicted a booming increase in human population by the year 2067, and the demand for livestock products is also expected to double by 2050 [1]. Currently, agriculture and animal husbandry employs more than 1.3 billion people and contribute 40% of world GDP [2]. In the future, the demand for dairy products is expected to grow as, Food and Agricultural Organization recommends daily consumption of dairy products for optimum health and nutrition [3].

The present challenge for the dairy sector is to optimize production and to adapt to unfavourable climatic conditions, mainly due to global warming. The global temperature has already increased by 1.5°C and there are predictions of future increases between 0.3 to 4.8°C by the end of the 21st century [4]. The impact of global warming will be direct as well as indirect on animal production systems, crop yield, soil fertility, pasture availability, water quality & quantity, vectors, pathogens, and parasites [5].

Over the years, our understanding of the effects of heat stress on animal welfare, health, and production has grown considerably and animals exposed to heat stress exhibit acclamatory physiological and metabolic responses, compromising growth, performance, and reducing milk and meat yield [6,7,8]. Today, several multi-integrated assessment models (IAM) like AIM/CGE, DNE21+, ENVLinkages, GCAM, IMAGE, MESSAGE-GLOBIOM, POLES, REMIND, and WITCH- GLOBIOM predict global warming, its deleterious consequences on the dairy sector and natural ecosystems, resulting in $ billion loss [9,10].

The urgency to comprehend the environmental impact, livestock and human population, production systems, available natural resources, and GHG, etc. on dairying, is much needed today.

Genetic improvement, production intensification, reducing carbon footprint, greenhouse gas emissions, and automation will be the key for successful dairying. So, scaling on the background, this review will explore some elemental transformations for a sustainable and profitable dairy enterprise in coming times.

Factors driving the global dairy industry and futuristic changes

There are many factors influencing and shaping the dairy industry and interaction of these different factors regulates the trends in dairy husbandry.

Global population

According to the United Nations world's population will increase from current population of 7.6 to 10.5 billion by the year 2067 mostly in Asia and Africa, putting an additional constraint on use of arable land for humans and animal food production [11]. A major shift from rural to urbanization has increased the per capita income and the use of animal products [12]. Comparatively, it is easier to produce dairy product having high quality protein and other nutritional elements for humans than meat and crops [13].

By the third quarter of 21st century the per capita consumption of dairy products is expected to increase to 119 kg from the present 87 kg/person, annually [14]. This can be only achieved is through increased milk production from dairy animals and reducing the production costs. An increase in both milk yield (27%) and animals (14%) are essential to sustain the future milk demand [15]. Regions having the highest number of dairy cattle like Asia, Africa and Brazil will have to maximize the milk production per animal to sustain the future milk demand [16]. The trend of higher milk production in these regions can be comprehended from table 1.

Fodder crops

In ruminants the digestion and assimilation of nutrients is a complex mechanism, which depends on many factors like microbiome, feed, fermentation, environmental conditions and animal health. Fodders with higher soluble carbohydrates like perennial maize and canes will be preferred over traditional crops to improve the gut microbiome activity [17,18,19]. As the world is getting warmer every decade, C4 fodder plants which have high environmental tolerance, use less water, grow faster and fix carbon more efficiently [20,21] will be the future choice as dairy fodder. Suitability will be decided on lower lignin content, higher digestibility, nitrogen fixing efficiency of the fodder [22].

Other less prevalent nutritional alternatives like spirulina, sea algae and various microalgae might be incorporated in cattle feeds (as supplementary feeds) and limiting the use of fertilizers and pesticides (phosphorus) to reduce the environmental impact will be essential. Artificial intelligence based robotic technology, will ensure optimum fodder production with precise point fertilizers and pesticides usage.

Dairy farms

The major categories of the dairy farms are household or small, medium and large, respectively. Dairy farms across the world grew till 2013, making the count to more than118 million dairy units [23]. Recently, Russia announced an expansion by planning to open 800 large dairy farms to sustain the ever-growing human population and trade [24]. Small dairy farms cutting their production costs can be more profitable [25], but as the number of animals increase larger farms become more profitable as they produce higher quality and quantity of milk [26,27].

Well organized big farms with larger herds are more profitable and have less carbon footprint, making them environment friendly. In future smaller farms can scale up profitability by production of specialized dairy products for targeted niche markets. However, globally there will be decline in total number of farms due to integration of medium dairy enterprises, as well as increased milk production per animal. With limited arable lands for the humans and livestock, the lateral and horizontal integration of the dairy industry will be essential for optimizing production, ensuring maximum dairy production eventually [16]. Some futuristic approaches are depicted in Figure 1.

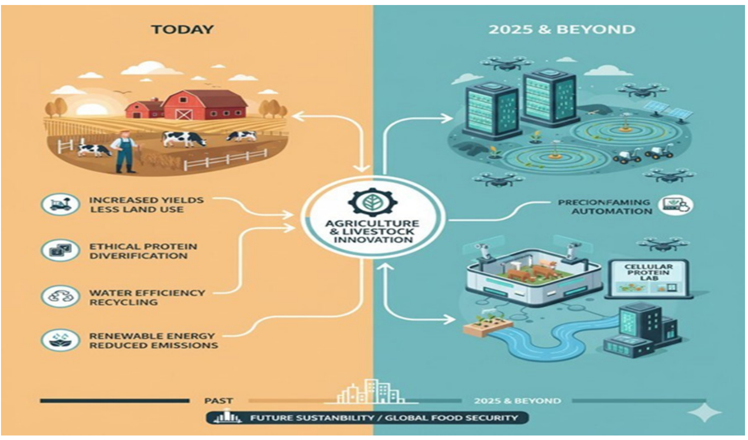

Figure 1: Future transitions for the sustainable Agri-Livestock enterprise.

It will also be pertinent to conserve the land for increasing human population, as we are currently using most of our arable and habitable land for either growing animal feed or as grazing lands. While, the land usage for dairy or beef cattle has remained almost same in the European and Oceania regions, its still growing in the Africa, Asia and Americas, respectively, which will intensify the land usage in future (Figure 2).

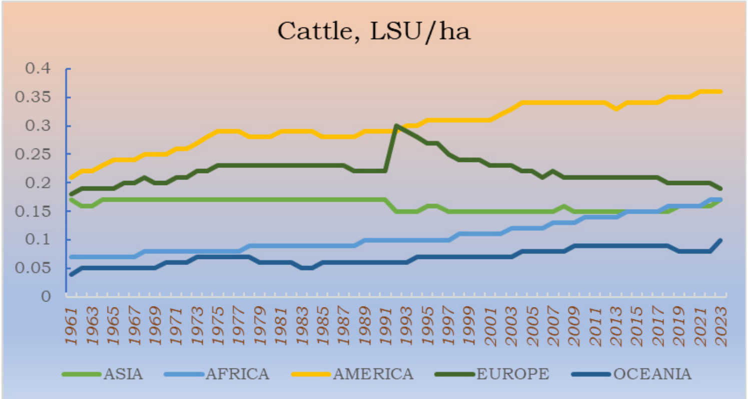

Figure 2: Livestock Unit utilization of Land Area, LSU/ha

Management of farm

Modernization and intensification of processing units increases the profitability and reduces product cost for consumers [28] therefore, focus will be on elevating the production, via technological integration on farms. In future use of environmentally controlled sheds, robotics, biosensors and artificial intelligence, as well as automation in feeding and milking will be adopted. Data integration will be via cloud-based technology for monitoring the animal health, welfare and production. Ultimately, machine learning and artificial intelligence will result in rapid, timely actions to improve animal health, breeding values, disease, parturition and heat monitoring and decrease overall production costs [29,30,31].

Milch animals and animals approaching parturition will be provided additional comfort and larger farms will have their own fodder plantations and processing units. To monitor and adjust feed intake correspondingly, with animal efficiency and milk yield, software's like TDIDT, ENET, SSD, ARIMA and CNNs are becoming prevalent [32,33,34]. A large part of farm will be dedicated for growing fodder to reduce production costs and sensor based and robotic technologies will be prevalently implemented. Disposal and utilization of all animal waste lead to the emergence of $ multimillion animal by product (urine, dung etc) industry like Patanjali in India, supporting and strengthening the farm economics. The cows will be mechanically, milked atleast 3 or 4 times a day to obtain maximum production and animal farm will be like a one super-colony, collectively monitored by machines, sensors and humans for 24 hours x 365 days, timeline.

Selection and management of animals

Earlier, irrational crossbreeding programs, adopted globally till mid-20th century have diluted the native germplasm, lowered the livestock vigor and reduced their resiliency to stress [35,36,37]. But in future, selective breeding programs and genomic enhancement will result into more vigorous, climate resilient cattle breeds. For example, genes from thermotolerant tropical cattle breeds (ex. SLICK gene) might be incorporated by CRISPR or other technologies in European or American cattle to improve adaptability to global warming [38]. Also, traits for resiliency, against adverse environmental conditions and diseases and better adaptability will be identified and incorporated in dairy cattle [39,40].

It becomes evident from table 1, that the total milk production over the years has grown most significantly in Asia and Africa, as compared to other continents. Highest growth change was noted for Asia and Africa during years, 2002-2023, while a decline was observed for Europe, Oceania and Americas (Table 1). The dairy breeds here are mostly adapted to cooler environmental conditions and have poor thermotolerance, which is the leading cause of decline in milk production [7].

Table 1: Global milk gross production index number.

Duration	World	Africa	Asia	America	Europe	Oceania
Duration wise % change						
1961-1981	36.94	64.04	71.15	23.41	34.47	5.48
1982-2001	24.45	60.91	130.81	35.99	-19.91	93.56
2002-2023	61.63	59.65	142.16	35.83	8.5	17.98
1961-2023	**188.41**	**376.22**	**915.46**	**136.41**	**20.21**	**158.13**

Reproductive efficiency in cattle will be monitored by biosensors and gestation period, dry period will be optimized by employing genomic selection and in vitro fertilization (IVF) technologies [41,42]. All information from the sensors will be assimilated at farm and the farm manager as well as veterinarian will be automatically notified for change in behaviors of sick animals, for timely interventions. Good flooring material will ensure animal movement, welfare curbing behavioral and lameness problems at farm to optimize welfare and production [43].

Human health and designer milk

Application of genetic engineering can produce of a specific bio-molecule or alter the structure and functions of an existing one in milk, for example increased production of an important nutriceutical protein, lactoferrrin. In the course of time, milk components will be added or deleted in breeds according to requirement and designer milk could be produced devoid of common allergens (casein and whey) or atherogenic compounds (casein, cholesterol, short-chain fatty acid, trans-isomers fatty acid). Similarly, the nutritional value or anti-bacterial or anticancerogenic (sphingomyelin, polyunsaturated fatty acids, butyric acids and lipid ethers) properties of designer milk could be enhanced [44].

Increased consumer health awareness and longevity of life has created an intensive demand for special types of dairy nutriceutical compounds like whey, whey isolates, casein, lactoferrin, bioactive peptides, immumoglobulins, lipids, phospholipids, glycolipids, oligosaccharides and Conjugated Linoleic Acid [45]. The future dairy industry will have to expand its nutriceutical product range in response to consumers changing tastes and demands [46]. However, availability of vegan soybean and nut-based milk products will make the market for dairy nutriceutical highly competitive [47].

Active ingredients in milk, its fermented products and colostrum contain biopeptides and other beneficial compounds like immunoglobulins, lactoferrin, latoperoxidase, and growth factors, which have potential health promoting pharmaceutical applications [48,49]. Soon, there will be emergence of dairy-pharmaceutical industry supplying dairy antioxidants and bioactive compounds for human health and medicine. Technological advancement will deliver, xenobiotics and pollutant free milk with bioactive peptides like, polyunsaturated fatty acids (especially DHA), phospholipids, cholesterol, some specific proteins, enzymes, hormones and growth factors, sCD14, lactoferrin, immunoglobulins, prebiotics/probiotics, and possibly miRNAs [50].

Targeting specific genders and age groups, for example milk similar to human milk or milk for women or milk for the elderly population [44] will be the key following for dairy industry. Nano-technological applications will improve the quality of milk and its processed products and bioactive compounds like encapsulated lipids, bioactive lipophilic compounds and reactive degradable packaging will be used to increase the shelf life, stability, palatability, desirability and bioactivity of the milk product [51]. Already in some countries, ultra-pasteurized and cultured dairy products are available for consumers [3]. The application of dairy probiotics for human health, wellness and obesity control appears very promising in nearing times [52].

Trade and government policies

Europe, New Zealand and Australia are the major exporters of milk and milk products in world but Asia and United States are also rapidly expanding their export markets. Then there was a global recession in 2008, decline in milk prices in 2014-15 [23], reduction in imports by china, changing Russian trade policies in 2013 [53] and abolition of milk quotas by EU-25 [54]. All these interactive factors contributed a steady decline in international dairy prices and export.

However, soon the bilateral and regional trade agreements amongst nations increased and there was tremendous growth in the export of dairy products and economic restructuring, primarily in the Asiatic and African continents [12]. Similarly, domestic consumption of milk, milk products and regulation of prices will be crucial especially for primary dairy exporters nations like, New Zealand, the European Union, the United States and Australia where the domestic market is already saturated [55, 56].

In the future, nations having adequate arable land, high yielding livestock, processing infrastructures and established market chains will be the major exporters of milk and dairy products [16] and country-oriented exports will create new challenges and new opportunities for emerging dairy economies [57]. The dairy sector will operate on financial (return over feed/cow, concentrate costs/kg milk, total feed costs/kg milk) and non-financial key performance indicators (KPIs) and trade will be regulated by fluctuations in milk and feed prices. Milk is and will always be one of the most volatile food commodities, but diversification of dairy products, permanent domestic and international markets, exploration of new markets and collaborative integration between public, private, government and non -profit organizations will ensure future sustainability and profitability.

Environmental impact

Livestock are one of the primary sources of GHGs, producing methane (from manure and enteric fermentation) and N2O (mainly from manure).

Additionally, the use of fertilizers for growing fodder crops compounds the problem of global warming. The global warming potential (GWP) differs with region, animal breed, managemental practices, removal and processing of waste materials. For example a New Zealand farming system contributes only 0.86 GWP/kg of milk, while in Western Europe it is 1.50 GWP/kg of milk [58].

Many leading dairy nations have already implemented short- and long-term policies to reduce the emission of GHGs, e.g. in Europe aims a 20% reduction in GHGs by 2020 and 20% use of renewable energy. Despite the GHGs emissions from the dairy sector, FAO confirms that milk and its products are the most efficient animal protein produced in terms of protein yield per acre.

Methane mitigation will require special policies and technological interventions like increasing feed efficiency, feed quality (protein, fats), use of additives (inophores, organic acids, mineral mixture, nitrate, sulphate salts), direct fed microbials (DFM) or probiotics, bacteriophages and bacteriocins [59]. Plant based secondary metabolites (PSM) like, tannins, flavonoids, saponins etc which target methanogens, enzyme additives to facilitate fiber digestibility and vaccination to eradicate or suppress the methanogenic bacteria's will be a routinely practiced [58,60].

Monitoring of gut microbiome and their manipulation will ensure highest feed efficiency and low or modest methane emissions in dairy animals. The future technologies will focus to curtail energy losses via methane emission (7-12 %, metabolic energy) and channelizing them for productive purposes, thus improving feed conversion and reducing production costs. Already, in Netherlands, research is underway to utilize methane for production of bioplastics, bio-textiles and bio-paper. Others are striving to convert methane into methanol or hydrocarbons or other useful product line [61]. On similar lines, composting and biofuel are two efficient options to reduce the cattle N2O emissions. The energy generated in process will further reduce energy requirement of the farm, making production profitable.

Different integrated assessment models (IAM) predict a steady rise in methane and carbon-dioxide levels (CO_2), but abatement of methane (from agriculture and livestock sector) will be more beneficial in near future to reduce the GHGs potential and global warming [10]. Similarly, priority will be to curb the CO_2 production and sequestration at carbon sinks like, direct removal, biochar, trapping in natural formations (geoengineering), afforestation, reforestation and blue carbon. Both mitigation of CO_2 and methane are the only options to meet the 2-degree target by 2100 [10,62]. Global organizations like Consumer Goods Forum and United Nations have adopted the motto "*Save food wastage for cleaner environment*" to make milk production and processing more efficient, to conserve energy and food losses by 2030 [63].

Conclusions and Final Considerations

Conservation of native animals, maximizing milk yield and production, balanced used of all natural resources, curtailing the impact of heat stress on dairy cattle, will be pertinent for prospective dairy industry. Dairy animals will be unlike what we see today and there will be specialized breed lines and oriented products. Dairy products will become potent pharmaco-bio-nutrients providing us key nutrition and wellness tomorrow. Regional, national and international trade policies will be key controllers for the future dairy economics. Eventually, artificial intelligence, biosensors and robotic technologies will manage our farms, cows and farming, and production-processing-distribution will be one single amalgamated process. For sustainable future of dairy industry going "green" will be essential from farm to fork as "*Future demands more milk and cleaner milk for humans*".

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