Climate Smart Technologies for Food Animal Production and Products

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**Kandeepan Gurunathan, Shahaji Phand,
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This e-book is a compilation of resource text obtained from various subject experts for Collaborative Online Training Programme of ICAR-NRCM & MANAGE, Hyderabad, Telangana on Climate Smart Technologies for Food Animal Production and Products conducted from 19-23 April, 2021. This e-book is designed to educate extension workers, students, and research scholars, academicians related to veterinary science and animal husbandry about climate smart technologies for food animal production and products.

MESSAGE

National Institute of Agricultural Extension Management (MANAGE), Hyderabad is an autonomous organization under the Ministry of Agriculture & Farmers Welfare, Government of India. The policies of liberalization and globalization of the economy and the level of agricultural technology becoming more sophisticated and complex, calls for major initiatives towards reorientation and modernization of the agricultural extension system. Effective ways of managing the extension system needed to be evolved and extension organizations enabled to transform the existing set up through professional guidance and training of critical manpower. MANAGE is the response to this imperative need. Agricultural extension to be effective, demands sound technological knowledge to the extension functionaries and therefore MANAGE has focused on training program on technological aspect in collaboration with ICAR institutions and state agriculture/veterinary universities, having expertise and facilities to organize technical training program for extension functionaries of state department.

In India, livestock products contribute mainly to the livelihood of the economically weaker sections of the society. The export earnings from different livestock products is also noticeably contributing to the national income. Indian livestock sector is regarded as one of the major source of greenhouse gas emissions contributing to global warming. This raises the issue of sustainability of livestock value chain in spite of high demand of meat and milk. In this context the innovative technologies to mitigate the GHG emissions would pave way for sustainability.

It is a pleasure to note that, ICAR-National Research Center on Meat, and MANAGE, Hyderabad, Telangana is organizing a collaborative training program on “Climate Smart Technologies for Food Animal Production and Products” from 19-23 April, 2021 and coming up with a joint publication as e-book on “Climate Smart Technologies for Food Animal Production and Products” as immediate outcome of the training program.

I wish the program be very purposeful and meaningful to the participants and also the e-book will be useful for stakeholders across the country. I extend my best wishes for success of the program and also I wish ICAR-National Research Center on Meat, Hyderabad, Telangana many more glorious years in service of Indian agriculture and allied sector ultimately benefitting the farmers. I would like to compliment the efforts of Dr. Shahaji Phand, Center Head-EAAS, MANAGE and the Director, ICAR-NRCM, Hyderabad for this valuable publication.

Dr. P. Chandra Shekara
Director General, MANAGE

FOREWORD

Livestock products are essential for the nutritional security in India and the world. Of late Indian animal husbandry sector is figured out as the major source of greenhouse gas emissions contributing to global warming. India is a vast country with largest livestock population in the world spread across with different geographical area. Indian livestock are reared with minimum inputs under grassland conditions. Animal husbandry activities are especially beneficial to the small and marginal farmers. The livestock products such as milk and meat play an important role in the socioeconomic life of Indian farmers. They have become essential commodity with great economic value. The production and processing of livestock products need to adopt various strategies with the changing climatic scenario.

In this context, ICAR-NRCM is conducting a free online training program on “Climate Smart Technologies for Food Animal Production and Products” sponsored by the National Institute of Agricultural Extension Management (MANAGE), Hyderabad for the Extension officials of state/central animal husbandry departments, veterinarians, faculty of SAUs/KVKs/ICAR institutes, etc. during 19-23, April 2021 through Cisco Webex Online Platform. The lectures of this online course are exactly designed to expose the participants to various aspects of climate resilient technologies for the production and processing of animal products. I hope that the participants from different parts of the country would be immensely benefitted from this online course by interactions with the expert resource persons selected for this training. I have no doubt that the course will be intellectually rewarding the participants.

I would like to take this opportunity to congratulate MANAGE and ICAR-NRCM for their fruitful collaboration towards benefits for the farmer community. I also congratulate the course director Dr.Kandeepan. G, Senior Scientist and course coordinators for their untiring work and high level of enthusiasm.

Dr. S.B.Barbuddhe
Director, ICAR-NRC on Meat

PREFACE

This e-book is an outcome of collaborative online training program on “Climate Smart Technologies for Food Animal Production and Products” conducted from 19-23 April, 2021. The editors’ main aim is to provide insights to all extension workers, faculties, researchers and students about climate resilient technologies for production and processing of livestock products. The extension people should know the entire value chain of livestock products. They can be benefitted from getting knowledge of various innovations in production and processing of animal products with regards to changing climatic scenario. The current information in the mitigation strategies to global warming due to animal product processing will help them to do well in the extension field.

The editors felt that all the experience of resource persons of this training should be clubbed together to form a unique proposition on climate smart innovations for food animal production and processing of livestock products. Milk and meat technology have far reached in ensuring the nutritional security of humankind. Technological solutions for sustainable production and processing of milk and meat under climate change is indeed a challenging job. The experts and resource persons in animal production and processing science contributed immensely and tirelessly to develop various chapters of this e-book in very short span of time. They all deserve appreciation. The editors extend their sincere thanks to all the experts who have contributed their valuable time and put sincere efforts to produce this e-book.

The editors also thank MANAGE, Hyderabad for the financial support for this training program. The editors express gratitude towards the Director, ICAR-NRC on Meat for the constant encouragement for this training and e-book creation for the participants. The editors hope that this e-book will help participants as well as other extension people across the country to gain valuable information on climate smart technologies for food animal production and processing of livestock products.

Editors

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Chapter 1

Climate change and livestock production: Current scenario and way forward

V.Sejian*, A. Devapriya, M.V.Silpa, M.R.Reshma Nair, C. Devaraj, G. Krishnan, M. Bagath, R.U. Suganthi, V.B. Awachat and Raghavendra Bhatta

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Introduction

Scientific evidence from multiple resources indicates that, without a doubt, climate is changing. It is also possible to suggest with increased confidence that climate is changing because of increased human activities which have serious repercussions on social and economic development. Livestock are livelihood security of weaker segment of the society having poor economic sustenance with lack of resources to create favorable microclimate in terms of shelter or intensive rearing in organized system. Global demand for livestock products is expected to double during the first half of this century as a result of the growing human population and its growing affluence. Over the same period, we expect big changes in the global climate. Today climate change is one of the most serious long-term challenges facing farmers and livestock owners around the globe. Climate change is widely considered to be one of the most potentially serious environmental problems ever confronting the global community. Besides being a major contributor to climate change, livestock play important roles in farming system in developing countries by providing food and income, draught power, fertilizer and soil conditioner, household energy and a means of disposing of otherwise unwanted crop residues. About 12 % of the world's population depends solely on livestock for their livelihood.

In Indian context, climate change is inducing an additional stress on the ecological and socioeconomic systems as they are already under tremendous pressures for various reasons including increasing population, rapid unplanned urbanization, industrialization and associated activities. The natural resources based economy makes India, as a Nation, all the more vulnerable in this perspective. The livestock sector contributes significantly to global warming through greenhouse gas (GHG) emissions. At the same time, livestock is an invaluable source of nutrition and livelihood for millions of poor people. Therefore, climate mitigation policies involving livestock must be designed with extreme care. Temperature and its associated seasonal patterns are critical components of agricultural production systems. Rising temperatures associated with climate change will likely have a detrimental impact on crop production, livestock, fishery and allied sectors. It is predicted that for every 2^0 C (which has been predicted by 2030) rise in temperature, the GDP will reduce by 5 per cent.

The continuous heat waves and drought as a result of climate change has impacted livestock production resulting in severe economic loss to the poor and marginal farmers in particular in India. Currently the impact of climate stress on milk production of dairy animals is estimated to be 1.8 million tonnes. Models based on different climatic scenarios suggest that milk production will decrease by 1.6 million tonnes by 2020 and by more than 15 million tonnes by 2050. North India is likely to experience greater climate related reduction in milk production of both cows and buffalos compared to other areas.

India holds the largest livestock population in the world, and among agriculture, livestock is the major subsector that has a great significance to the Indian economy and particularly for the welfare of the rural farmers in India. In India among the livestock population, small ruminants play an important role in the rural economy since most of the farmers are mainly poor and marginal farmers, they cannot afford the huge maintenance expenses on large ruminants compared to the small ruminants. Within small ruminants, goat rearing is considered one of the backbone of the Indian farming industry as it provides gainful employment to the farmers especially in the rural area. In the changing climatic scenario, goat is the most admirable animal for physiological and biomedical research especially in the field of establishing the impact of climate change on livestock production. Hence, research efforts are needed to study the adaptive capability of goat to their natural environment in the extensive system of rearing. As a result of climate change in the extensive system of rearing, small ruminants are exposed to several environmental stresses. This chapter is therefore an attempt to collate and synthesis information pertaining to vulnerability of small ruminant livestock to climate change and project to the audience the various impacts of climate change on small ruminant production and adaptation.

Climate Change and heat stress

Although many factors can be involved, climatic factors are among the first and crucial limiting factors of the development of animal production in warm regions. In addition, global warming will further accentuate heat stress related problems in livestock. The first and foremost stress the livestock are exposed as a result of CC is the heat stress. Among the environmental variables affecting animals, heat stress seems to be one of the intriguing factors making animal production challenging in many geographical locations in the world. Although animals can adapt to the hot climate, nevertheless the response mechanisms that ensures survival are also detrimental to performance. The vulnerability of livestock to heat stress varies according to species, genetic potential, life stage and nutritional status. By far heat stress seems to be the most important factors affecting drastically ruminant livestock production under changing climatic condition. Heat stress has severe consequences both on production and reproduction in livestock.

Impact of heat stress on livestock production

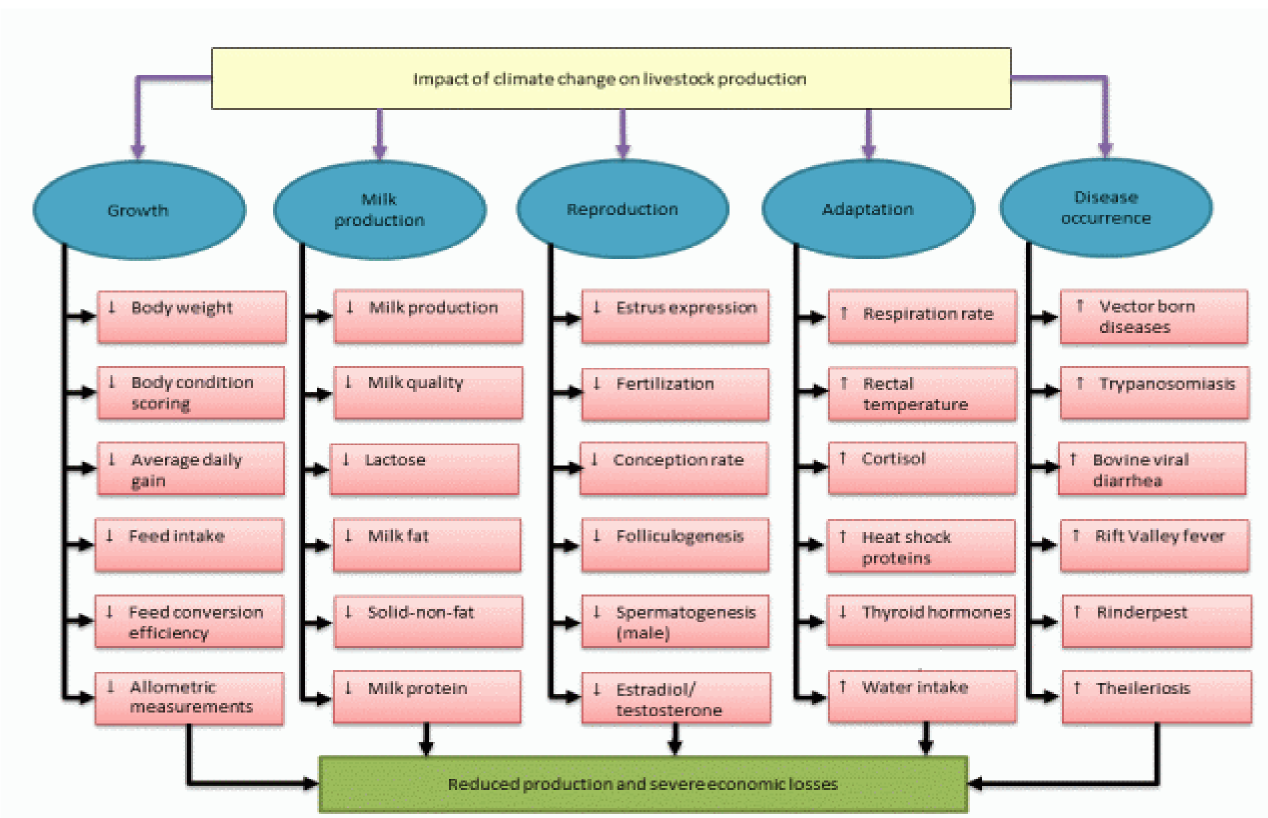

Fig. 1. Impact of climate change on livestock production

Impact of heat stress on livestock growth and milk production

Growth, the increase in the live body mass or cell multiplication, is controlled genetically and environmentally. Elevated ambient temperature is considered to be one of the environmental factors influencing average daily gain. The reason for the effects of elevated ambient temperature on growth reduction could be due to decrease in anabolic activity and the increase in tissue catabolism due to increase in catecholamines and glucocorticoids after exposure to heat stress in livestock. Livestock respond to a heat challenge by decreasing feed intake which then has a direct impact on performance for example reductions in milk yield, milk quality, meat and egg production. Heat stress particularly in dairy animals will have long term effects on both milk production and birth rates. Increased summer temperature leads to depressed and low feed intake, reduction in body weight of animals, and lower milk production. In addition the cellular and molecular stress responses have an effect on mammary gland metabolism, energy partitioning and immune status. Under extreme conditions there may also be an increase on mortality rates. All of these changes lead to economic loss. Biological effects on livestock due to global warming are not predictable simply in terms of a response to increased heat load. Among other things increasing temperature may also increase exposure, and susceptibility of animals to parasites and disease, especially vector-borne diseases. However, little effort has been dedicated to understanding the potential impact of CC on parasite populations and subsequent effects on animal production. Fig.1 describes the various impacts of climate change on livestock production

Ambient temperature plays a major role whereas increased temperatures and humidity levels causes the animals to have increased body temperatures, which results in declined feed intake, disturbed reproductive functions, and low milk yield. High temperature and increased thermal stress also negatively impact ovarian activity, especially in buffalo, and crossbred cows that are known to have a poor capacity to dissipate heat from the skin. Limited availability of water could further impact reproductive functions and also milk production. Currently the impact of climate stress on milk production of dairy animals is estimated to be 1.8 million tonnes. Models based on different climatic scenarios suggest that milk production will decrease by 1.6 million tonnes by 2020 and by more than 15 million tonnes by 2050. North India is likely to experience greater climate related reduction in milk production of both cows and buffalos compared to other areas.

Impact of heat stress on meat production

Significant research has been done on heat stress impacts on meat quality and composition especially in cattle, sheep, goat, pig and broilers. High temperature and humidity results in increased meat pH, less expressed juice, cooking loss and drip loss. During exposure to high temperatures the energy utilization gets decreased while the energy expenditure is increased for thermoregulation. This deteriorates the quality of the meat by decreasing the muscle glycogen leading to increase in the muscle pH. The functional properties of meat such as color, water holding capacity (WHC) and myofibrillar fragmentation index (MFI) were also negatively influenced during heat stress in ruminants. Further, the animal management practices during climate change also can indirectly affect the meat quality. For example, rearing heat-tolerant *Bos indicus* cattle is an effective adaptation strategy against the prevailing harsh climatic conditions. This can lead to tougher and less juicy beef. Besides the qualitative alterations driven by the heat load on the animals, carcass weight losses in heat stressed animals also has economic significance. Ante-mortem temperature stress is a major determinant for live carcass weight losses, hot carcass weight and retail meat yield. Energy partitioning for thermoregulation accompanied with reduced feed intake to reduce heat load resulted in live weight losses. From these findings it is evident that heat stress declines both qualitative and quantitative characteristics of meat. However, this adverse effect of heat stress on meat quality is variable based on the region of animal origin. This warrents developing region specific appropriate strategies to cope up with heat stress to improve meat production in the changing climate scenario.Fig.2 describes the various impacts of heat stress on goat meat production.

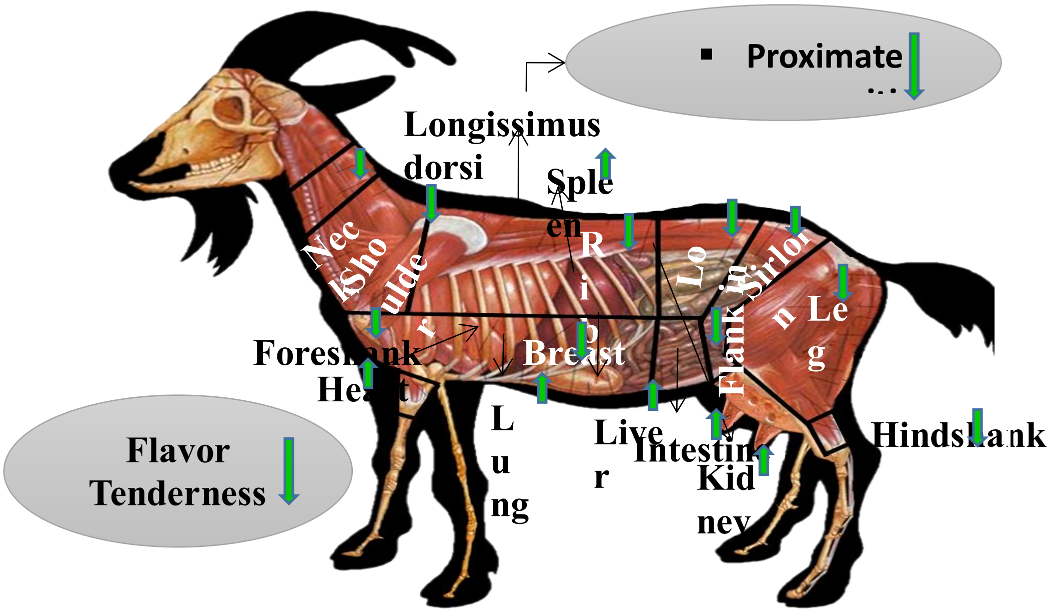

Fig. 2. Impact of heat stress on goat meat production

Impact of heat stress on livestock reproduction

Reproductive fitness may be regarded as the most important criterion relating to adaptation. Systems activated by stress can influence reproduction at the hypothalamus, pituitary gland or gonads. However, the major impact is thought to be within the brain or at the pituitary gland. Activation of stress pathways may directly affect the activity of GnRH neurons within the hypothalamus or higher neural centres that project to GnRH neurons and, therefore, the synthesis or secretion of GnRH into the hypophysial portal blood. It is also possible that stress directly influences the responsiveness of gonadotroph cells in the anterior pituitary gland to the actions of GnRH. A further potential action of stress is to alter the feedback actions of sex steroids in the hypothalamus or pituitary and of inhibin in the anterior pituitary gland. It is an established fact that reproduction processes are influenced during thermal exposure and glucocorticoids are paramount in mediating the inhibitory effects of stress on reproduction. Further, glucocorticoids are capable of enhancing the negative feedback effects of estradiol and reducing the stimulation of GnRH receptor expression by estrogen. Glucocorticoids may also exert direct inhibitory effects on gonadal steroid secretion and sensitivity of target tissues to sex steroids. Fig.3 describes the various impacts of heat stress on dairy cow reproduction.

Reproductive processes in the male and female animal are very sensitive to disruption by hyperthermia, with the most pronounced consequences being reduced quantity and quality of sperm production in males and decreased fertility in females. Under heat stress the physiological and cellular aspects of reproductive function are disrupted by either the increase in body temperature caused by heat stress or by the physiological adaptations engaged by the animal to reduce hyperthermia.

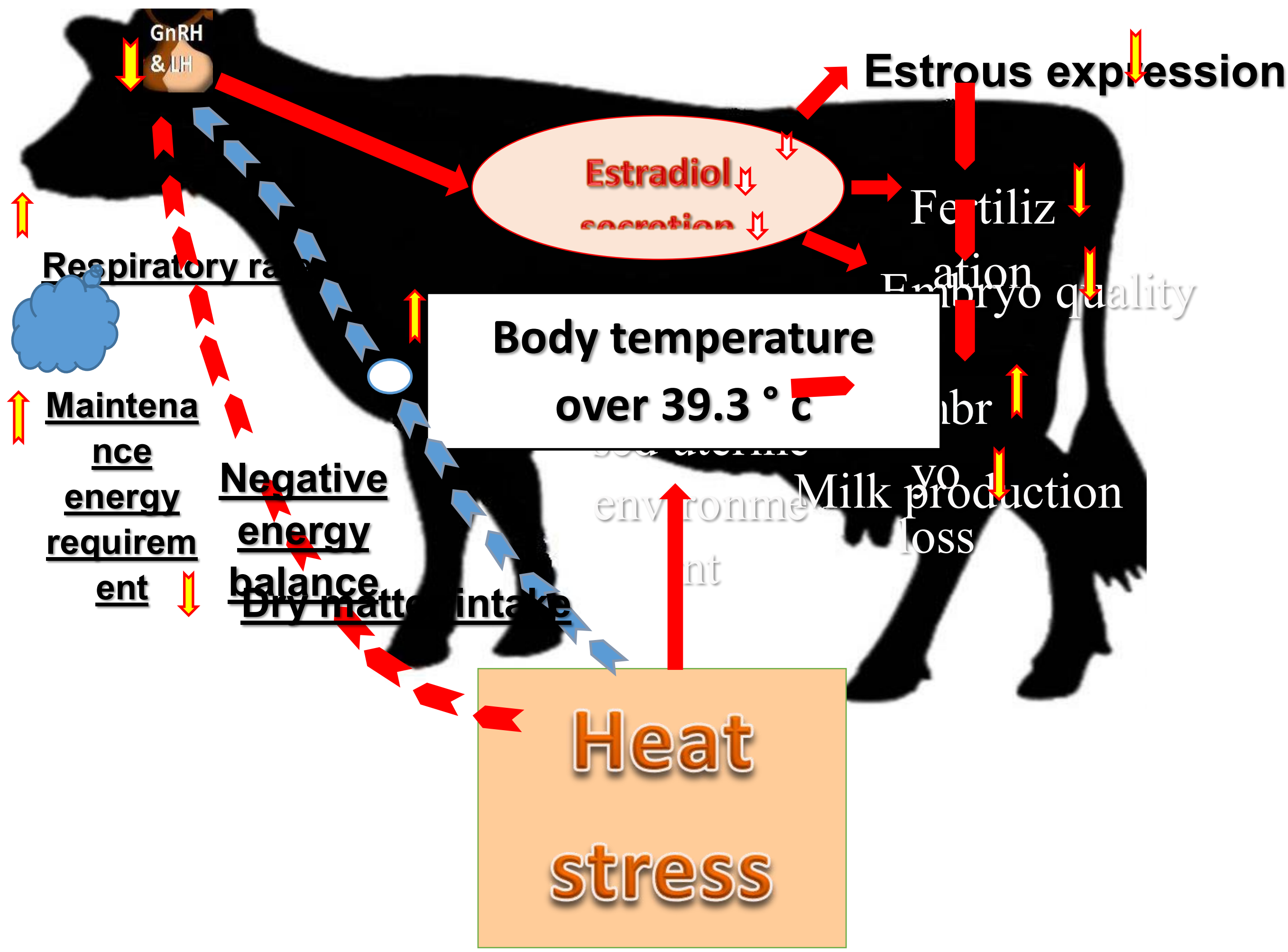

Fig.3. Pictorial representation of impact of heat stress on dairy cow production

3. Importance of minimizing climatic change on animal husbandry

In agricultural and animal production to control and decrease emission of harmful gases has become important in environmental protection. It should be noticed that certain gases released in agriculture/animal husbandry production, such as methane, carbon dioxide, nitrous oxide and ammonia, directly affect global climate change which influences the development of social economy by acting on agriculture animal husbandry and water resources. If the warming of global climate is continually accelerated, it is possible that further increase in occurrence of flood and drought will occur. Because of the deterioration in water supply, demand of agriculture and pasture the shortage of water will become more serious and the quantity and quality of herbage will largely decline. The increase of temperature will lead to the decline in the yield of crops so also decrease the forage for livestock resulting in decrease of animal production and reproduction performance to different degree. Climate change also will influence of etiologic bacteria and parasites on livestock. Therefore in order to avoid disaster of global environment and prevent it from further deterioration, it is a vital matter of immediate urgency to maintain and control density of greenhouse gases in atmosphere.

Climate change and climate change mitigation will bring about major structural change in the agriculture, forestry and other land use sectors. With effective global action, climate change mitigation would become the more important force for change. A rising carbon price will alter the cost of land management practices and commodities, depending on their emissions profiles. Domestic food production in many developing countries will be at immediate risk of reductions in agricultural productivity due to crop failure, livestock loss, severe weather events and new patterns of pests and diseases. Climate change could disrupt ocean currents, which would have serious ramifications on the availability of fish, a major protein source. Farmers in developing countries lesser posses options to adapt to and effectively manage these risks due to the higher proportion of small-scale and subsistence farms, poorly developed infrastructure and lesser access to capital and technology. These impacts, together with the considerable increases in population and food demand expected in developing countries, will lead to an increase in global food prices.

4. Strategies to sustain livestock production in the changing climate scenario

Fig. 4. Describes the different approaches for ameliorating the impact of environmental stresses in livestock

4.1. Management strategies to improve dairy production in the changing climate

Animal housing is one of the approaches to alleviate the impacts of climate change on cattle. Shade reduces the severity of heat stress in animals that are being exposed to sun. It is an effective method to protect the animals from radiant heat load and helps to cool the animals. Shades can be made artificial or natural. Aluminum or galvanized steel roofs are artificial shades while the roofs made out of straw are of natural means. Provision of trees and other vegetative covers over the surrounding area will reduce the effect of radiative heat load on the cattle. Roofing materials should always be a bad conductor of heat and the best housing will have roofs painted in white so as to reflect the radiation of sun. Physical protection with artificial or natural shade presently offers the most immediate and cost-effective approach for enhancing reproductive efficiency of animals. Evaporative cooling also can be effective. Various shade management systems have been evaluated extensively and generally result in improved feed intake and productivity. The orientation of the shed should be in north-south direction in the northern hemisphere so that the direct incidence of solar radiation into the shed is avoided. For effective heat dissipation in cattle, there should be free flow of air inside the shed, this can be done by increasing the ventilation by means such as keeping half side wall i.e., open housing system, use of fan, increasing the height of the building etc. Shade alone will reduce a cow's respiration rate by 30%, and adding sprinklers will reduce the respiration rate by 67%. Both methods of cooling will also lower rectal temperatures. Use of shade plus fans and sprinklers has an additive effect. Use of fans is important, especially in confined structures, because fans help to move warm air from cows' bodies.

One of the best practices to reduce heat stress is to provide adequate fresh, cool, clean drinking water. Other methods of cooling include shade, commercial coolers, tunnel ventilation, shower/fanning stations, fans, cooling ponds and center pivots. Cows generate approximately 20% of their gross energy as body heat, which is released to the surrounding air, making them feel hot, especially under heat stress conditions. Fans remove this body heat via convection, thereby cooling down the surface of the animal. Sprinklers are used to soak the cow's hair coat to the skin with water, allowing the loss of body heat via conduction. Fans plus sprinklers allow for conduction and evaporative cooling, as the fans help to vaporize the water that has been warmed by the release of body heat. Marked relief was observed in cows by the use of fans plus sprinklers, which reduced respiration by 50% to 50 breaths per minute.

Water and air movement becomes the major agents by which the microenvironment inside the barn is cooled and evaporative cooling by the animals is augmented. Enhancing heat loss with the help of sprinklers/misters/foggers along with fans and installation of air conditioners in extreme hot climates are the main strategies for mitigating the heat stress. Sprinkling animal in the morning is more effective than sprinkling in the afternoon. Certainly it is recommended to start cooling strategies prior to animal showing signs of heat stress (panting). Sprinkling of pen surfaces may be as much or more beneficial than sprinkling the animal. Cooling the surface would appear to provide a heat sink for animal to dissipate body heat, thus allowing animal to better adapt to environmental conditions vs adapting to being wetted. In handling studies, moving animal through working facilities requires an expenditure of energy causing an elevation of average body temperature between 0.5 and 1.0 °C (.9 and 1.8 °F), depending on the ambient conditions. So during hot days minimal handling of animal is recommended for promoting animal comfort. Some farmers even acclimatize their animals intentionally by exposing them to artificial thermal conditions in order to prepare themselves before the season and thus preventing stress losses. Reducing the stocking density during hot weather will help the animals in dissipating the body heat more efficiently and during cold conditions the stocking density can be increased. And also the cattle should be provided bedding and warmth to protect them from extreme cold weather.

4.2. Nutritional strategies to manage dairy cattle under changing climate

During hot dry summer there is decrease in dietary feed intake which is responsible for the reduced productivity. In this situation the efficient practical approaches like frequent feeding, improved forage quality, use of palatable feeds, good nutrition balance and greater nutrient density are required. Because there is greater heat production associated with metabolism of acetate compared with propionate, there is a logical rationale for the practice of feeding low fiber rations during hot weather. Changes in diet are needed during hot weather to maintain nutrient intake in order to maintain homeostasis. Optimizing ruminally undegraded protein improves milk yield in hot climates. The recommended level of crude protein in the diet should not exceed 18 % and the level of rumen degradable protein should not exceed 61 % of crude protein. The Mineral losses via sweating especially potassium and changes in blood acid-base chemistry resulting from hyperventilation reduce blood bicarbonate and blood buffering capacity and increase urinary excretion of electrolytes and as a result the supplementation of electrolytes are essential. Of the three main rumen-produced volatile fatty acids, propionate is the one primarily converted into glucose by the liver. Highly fermentable starches such as grains increase rumen propionate production, and although propionate is the primary glucose precursor, feeding additional grains can be risky as heat stressed cows are already susceptible to rumen acidosis. Heat production is lower when the cattle are fed with feed ingredients such as concentrates and fats, whereas forages have a greater heat increment and in addition to that the feeding of high fibrous diets will lead to production of more acetate which has more heat of nutrient metabolism in comparison to propionate. Ruminant diets with grain and low fiber produce less heat stress for lactating cow because of their lower heat of digestion. However a good quality of roughages should be fed in order to prevent acidosis. Improved dietary energy density and the lower heat increment associated with the inclusion of dietary fat must be coupled with limitations to fat feeding to avoid ruminal and metabolic disorders. There are studies demonstrating that dietary fat can be added to the ration at up to 3–5% without any adverse effects to ruminal micro flora. Improved efficiency and lower heat increments should make fat especially beneficial during hot weather. Ruminally protected fats allow the inclusion of a substantial quantity of fat in the diet, which could lower heat increment significantly. Supplementation of saturated fatty acids at 1.5 or 3.0% of diet dry matter increases the milk yield, milk fat content and yield, and reduces the peak rectal temperatures in heat stressed cows. The feeding time also has great significance as the feeding behavior of the animal changes, studies state that feeding during the cooler hours of the day and also increasing the number of daily feeding proves beneficial against the heat stress. Increasing the feeding frequency will also help to minimize the diurnal fluctuations in ruminal metabolites, increase the feed utilization efficiency in the rumen and it further enhances the animal's ability to cop up with the heat load during the summer.

Addition of monenesin increases propionate production. In addition, monensin may assist in stabilizing rumen pH during stress situations. Propylene glycol is also typically fed in early lactation that may be an effective method of increasing propionate production during heat stress. In a study where heifers were supplemented with increasing amounts of chromium the insulin sensitivity increased, suggesting that chromium plays an essential role in glucose metabolism in ruminants. Because glucose use predominates during heat stress, chromium supplementation may improve thermal tolerance or production in heat-stressed animals. For instance, supplementing heat-stressed early lactation dairy cows with chromium reduced the degree of weight loss, improved milk production, reduced the concentration of plasma non esterified fatty acid (NEFA) and improved rebreeding rates. Feed additives like Niacin, Na bicarbonate buffer, antioxidants, fungal yeast culture, Lipoic acid and Thiazolidinediones supplementations are good practices for alleviating heat stress. Somatotrophin treatment in cows is known to increase the milk yield upto 15 % in even severely heat-stressed dairy cows. In addition to all these *ad libitum* quantity of non-contaminated water should be provided as it is a crucial necessity for livestock survival and productivity. It is a well-established fact that during heat stresses the water requirement of the animal increases about 2 to 4 times. Water management strategies for both surface and ground water resources should be undertaken like interlinking of rivers, integrated water resource management, improved water harvesting techniques etc. at both local and national levels. Another major constraint in the tropics is the non-availability of the feed resources during the summer. This can be overcome by the use of non-conventional feed resources like castor bean meal, neem seed cake, tomato pulp, vegetable wastes, pineapple silage, azolla, areca sheath etc. Also the forage management practices like growing of hydroponic grasses, silage preparation, feeding of hay and growing of summer or drought tolerant varieties like Bahia grass.

Nutritional tools, such as antioxidant feeding (Vit-A, selenium, zinc etc.) and ruminant specific live yeast can help. Studies have shown that addition of antioxidant in diets of cows is able to reduce stress and is a good strategy to prevent mastitis, optimize feed intake and reduce the negative impact of heat stress on milk production. Moreover, the use of antioxidant such as Vit-E, Vit-A, selenium and selenium enriched yeast help reducing the impact of heat stress on the oxidant balance, resulting in improved milk quality and cow health. A recent study in cattle showed that the supplementation of Vit-E help in reducing the heat stress and improves the antioxidant status and lowers the incidence of mastitis, metritis, and retention of placenta.

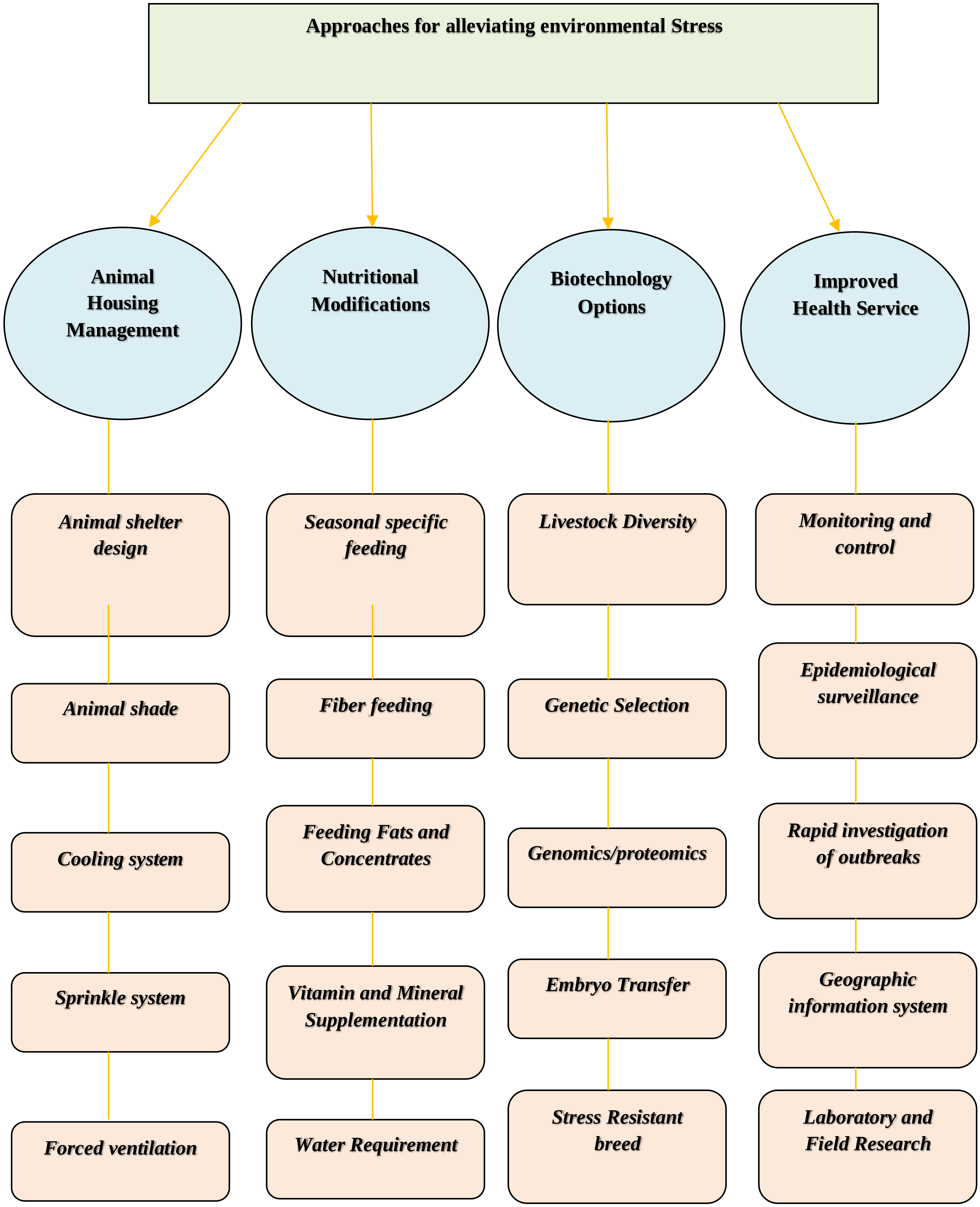

Fig. 4. Different approaches for ameliorating the impact of environmental stresses in livestock

4.3. Exploiting the genetic potential of local/indigenous breeds to counter climate change impact

In the face of changing climate scenario, efforts are needed to exploit the genetic potential of indigenous livestock breeds of different species. Productive traits need to be targeted to assess the performance of such indigenous breeds. After thorough assessment appropriate breeds needs to be developed which are able to survive to the local environmental conditions. With the advancement in molecular biotechnological tools, it is possible to identify and characterize genes responsible to adapt to drought and heat stress. Efforts are also equally needed to carry out several simulation studies involving programming various ranges of temperature and humidity in the climate controlled chambers. Such efforts can help to identify important biomarkers for climate change associated environmental stresses which can be used in Marker Assisted Selection (MAS) breeding to evolve suitable breed which has the ability to survive in different agro-ecological zones in India.

5. Conclusions

Scientific research can help the livestock sector in the battle against climate change. All animal scientists must collaborate closely with colleagues of other disciplines, first with agronomists then, physicists, meteorologists, engineers, economists, etc. The effort in selecting animals that up to now has been primarily oriented toward productive traits, from now on, must be oriented toward robustness, and above all adaptability to heat stress. In this way molecular biology could allow to directly achieve genotypes with the necessary phenotypic characteristics. Research must continue developing new techniques of cooling systems such as thermo-isolation, concentrating more than in the past on techniques requiring low energy expenditure. New indices that are more complete than THI to evaluate the climatic effects on each animal species must be developed and weather forecast reports must also be developed with these indices, to inform the farmers in advance. Above all to beat the climate change or in any case not to let the climate beat livestock systems, researchers must be very aware of technologies of water conservation.

6. Future perspectives

Responding to the challenges of global warming necessitate a paradigm shift in the practice of agriculture and in the role of livestock within the farming system. Science and technology are lacking in thematic issues, including those related to climatic adaptation, dissemination of new understandings in rangeland ecology, and a holistic understanding of pastoral resource management. The key thematic issues on environment stress and livestock production includes: early warning system, multiple stress research, simultaneously, simulation models, water experiments, exploitation of genetic potential of native breeds, suitable breeding programme and nutritional intervention research. Livestock farmers should have key roles in determining what adaptation and mitigation strategies they support if these have to sustain livestock production in changing climate. The integration of new technologies into the research and technology transfer systems potentially offers many opportunities to further the development of climate change adaptation strategies.

Suggested Reading

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Chapter 2

Climate smart livestock production and processing: An approach for sustainable food security

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India is required to ensure freedom from poverty, hunger and malnutrition in order to meet United Nations-mandated Sustainable Development Goal (SDG) No. 1 (no poverty) and 2 (zero hunger) by 2030. NITI Aayog, the government think tank has recently released the second edition of the SDG *India Index and has reported improvement in* India's composite score for SDG from 57 in 2018 to 60 in 2019 with maximum improvements in Goal 6 (clean water and sanitation), 7 (affordable and clean energy) and 9 (industry, innovation and infrastructure).

Globally one in seven humans are undernourished. More than half a billion people in developing countries depend in whole or in part on farm animals for their livelihood. Around 821 million people are undernourished mainly proteins and micronutrients that are readily available in animal sourced foods. Hence, global production and consumption of meat continue to surge as demand is driven upward by population growth, individual economic gain, and urbanization. In 2012, the Food and Agriculture Organization (FAO) of the United Nations projected the global demand for meat would reach 455M metric tons by 2050 (a 76% increase from 2005). The majority of this demand is attributed to middle/low-income countries (e.g., China, India and Africa) where demand for animal sourced foods is increasing at a much faster pace. 200 million Indians still cannot afford three square meals a day and India is experiencing "Protein Inflation". India ranks 102nd among 117 countries in Global Hunger Index. The 38.4% children have stunted growth, 57% children with vitamin-A deficiency and 40% people are anemic (Naveena et al., 2020). India has produced 8.1 million tonnes of meat in the year 2018-19 and it is expected that by 2030, the country needs around 12.1 MT in most likely scenario. Both in India and also globally, the meat production and consumption is increasing over the years and it will continue to increase owing to greater demand for animal sourced proteins.

The food and agricultural sector offers key solutions for development, and is central for hunger and poverty eradication. Livestock can feed and sustain today's population and tomorrow's in a way that is sustainable, environmentally friendly and economically inclusive. Animal sourced proteins must be targeted towards providing a healthy diet in a sustainable manner without compromising ecology and environment. This involves commitment from Government, Industries and stakeholders including consumers. Sustainability of livestock and meat sector is ensured through climate smart production technologies wherein livestock and environment interact with each other. Climate smart production involves increasing the productivity, reducing the green-house emissions and enhancing the resilience through optimal land, water and energy usage. Following section describe the impact of livestock and meat production on climate and importance of livestock, meat and poultry sector for livelihood, economy and nutritional security.

Livestock sector and water usage

70% of planet is covered by water but only 2.5% is fresh and drinkable. According available literature, global average water footprint mainly from developed countries ranges from 15,400 litres/kg for beef, 10,400 litres/kg sheep, 6000 litres/kg pig, 5,500 litres/kg goat and 4300 litres/kg chicken. Milk, eggs and cheese ranges from 1020 litres/kg, 3300 litres/kg and 5060 litres/kg respectively (Table 1). More than 90% of water used in livestock production is used for feed production. These figures may be true for developed countries wherein livestock are mainly fed with grains and concentrates. However, under Indian conditions with majority of livestock rearing activities under extensive or semi-intensive conditions mainly fed with green fodder or hay and or/agricultural by-products the aforesaid water footprint values may not be applicable. As per Industry reports in India, each water-buffalo slaughtering and processing consumes around 100 litres of water and each kg of hygienic chicken processing consumes around 5-8 litres/kg in India.

Table 1. Average water footprint values for important plant and animal sourced foods

Item	**Litres of water/kg**
Rice	3000-5000
Cotton	22,500
Sugarcane	1500-3000
Roasted coffee	18,900
Chicken	4300
Milk	1020
Egg	3300

(Source: Naveena et al. 2020)

Livestock sector, feed and land usage

a. The prospects of zoonotic pandemics or of human triggered climate change are real and growing. It is a global challenge to address the livestock and environment interaction and their impact on climate, water and land use, nutrient recycling and biodiversity. Livestock sector presents a safe, environmentally sustainable and affordable opportunity to address human triggered climate change.

b. Globally 1.0 billion tonnes of wheat, barley, oats, rye, maize, sorghum and millet poured annually into livestock troughs which could feed 3.5 billion humans. However, health benefits of eating modest amounts of meat and crop and livestock farming complementing each other must be considered.

c. Globally more than half (57%) of the 2.5 billion hectares of land used for producing forage is unsuitable for human food production (Mottet et al., 2017).

d. 4.7% of total cultivable land in India is used for growing dry and green fodder (edible) and 10% of this is in Punjab. Farmers are moving from cereals to cash crops (lees fodder) and thereby non-availability of agricultural by-products.

e. In India, majorly the land which is not suitable for growing human foods is being used for livestock production or feed production. Feed stuffs of little or no value to human beings is converted into high quality milk and meat with balanced proteins and micro-nutrients. The rumen of cattle, buffalo, sheep and goat are filled with trillions of microbes that can breakdown human inedible plants. The rumen microbes give ruminant animals their upcycling super-power to upgrade plants of little or nil nutritional value to human beings to high quality protein, micronutrients and other important products. As per the reports from beef research organization, USA grain finished beef cattle (90% forage + 10% grain) provide 19% more human-edible protein than they consume.

f. Only 14% of feed consumed by livestock is edible to humans, the remaining 86%, including by-products, crop residues, and grasses or fodder, is converted into human food contributing to incomes and avoiding environmental pollution from burning and dumping the residues and by-products (Mottet et al., 2017).

g. Scientific intervention through nutritional, genetic, health and management strategies to reduce GHG emission intensities by as much as 30% (Gerber et al., 2013).

h. Relative differences in carbon footprints between animals versus plant foods don't add up to significant GHG-emission differences at the National level. If the amount of animal sourced proteins and micro-nutrients have to be replaced by the vegetarian food, the quantity of synthetic fertilizer usage and soil erosion need to be considered.

i. Need to Understand *"Diversity of Livestock Production System"* in India

Livestock sector and environment

- According the Food and Agriculture Organization (FAO) of the United Nations, livestock including dairy contributes about 14.5% of global greenhouse gas emissions (mainly carbon dioxide, nitrous oxide and methane), whilst providing 28% of protein in diets. As per the Greenhouse Gas Emission (GHG) platform report in the year 2013, in India 63% of green-house gas emission is contributed by energy sector, 26% by Industries and 7% by agriculture, forestry and other land use sector (AFOLU), whereas 4% from water. The 80% of AFOLU contribution comes from rice cultivation and livestock.
- A cow produces up to 70 kg manure per day, providing enough fertilizer in a year for one hectare of wheat, equivalent to 128 kg synthetic nitrogen. An average of 45-50 kg manure (liquid + solid) is produced each day for a dairy cow and 25-30 kg per day for beef cattle. Animal manure is an asset if fertilizers are unavailable or expensive.
- Greenhouse gas emission intensity is reduced by increased productivity per animal. Strategies for increased productivity include ration balancing in smallholder operations and small grain supplements to ruminants fed high-forage diets. Group feeding dairy cows according to production and feeding diets higher in rumen-undegraded protein can improve milk and protein yield.
- Livestock production offers the greatest potential to reduce greenhouse gas emission from agriculture- up to 30% (Varijakshapanicker et al., 2019)
- However, poorly managed livestock systems may have adverse effects on the environment and human and animal health and welfare.

Livestock production contributes to sustainability through

1. Use of uncultivable land for food production
2. Conversion of energy and protein sources that cannot be used by humans into highly nutritious animal sourced food

3. Reduction of environmental pollution with agro-industrial by-products
4. Generation of income and supporting livelihoods of millions of people all over the world.

Steps to Sustainable Livestock (Source: Eisler et al. 2014: Nature)

1. Feed animals less human food
2. Raise regionally appropriate animals
3. Keep animals healthy
4. Adopt smart supplements
5. Eat quality not quantity
6. Tailor practices to local culture
7. Track costs and benefits
8. Study best practices

Conclusion

Livestock can feed and sustain today's population and tomorrow's in a way that is sustainable, environmentally friendly and economically inclusive. Livestock production systems need to evolve to meet some major concerns of 21st century societies and we believe that research can help guide that evolution.

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Chapter 3

Smart packaging of meat and meat products: A possible solution for climate change

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1. Introduction

Packaging has become the third largest industry in the world and it represents about 2% of Gross National Product (GNP) in developed countries. The fundamental reasons for packaging fresh and processed meat products are preventing contamination, delaying spoilage, permitting some enzymatic activity to improve tenderness, reducing weight loss, and retaining colour and aroma. Based on this, the current meat packaging practices range from overwrap packaging for short-term chilled storage and/or retail display, to vacuum packaging, bulk-gas flushing or modified atmosphere packaging (MAP) systems for long-term chilled storage, each with different attributes and applications. Recently, a series of new packaging technologies and materials have been developed including active packaging, intelligent packaging, edible coatings/films, biodegradable packaging, and nanomaterial packaging. These technologies and materials have the potential to improve the quality and safety, prolong the self-life, reduce the environment impact, and increase the attractiveness of the packaged product to the retailers and consumers, outcomes that are favourably welcomed by the food industry.

2. Recent developments in meat packaging

Innovative packaging with enhanced functions is constantly sought in response to the consumer demands for minimally processed foods with fewer preservatives, increased regulatory requirements, market globalization, concern for food safety, and the threat of food bioterrorism. Active packaging, intelligent packaging, edible coatings/films and biodegradable packaging, and nanotechnology are the major recent innovations in the food packaging industry that have shown promising advanced properties in extending shelf life, improving food safety and quality, and protecting our natural environment. The characteristics for selection of suitable packaging material for packaging of a particular product are given in Table 1.

Table 1. Properties of major packaging materials used for meat and poultry (Robertson, 2006; Osswald et al., 2006)

Packaging material (0.025 mm thickness)	Water vapour transmission rate, g/m2/24 h	O2 transmission rate, cm3/m2/24 h	Tensile strength, MPa	Tear strength, g/mL	Impact strength, J/m	Haze, %	Light Transmis-sion, %	Heat seal temperature range, °C
Poly(vinyl chloride) PVC	1.5–5	8–25	9–45	400–700	180–290	1–2	90	135–170
Poly vinylidene chloride (PVdC)	0.5–1	2–4	55–110	10–19	–	1–5	90	120–150
Polypropylene, PP	5–12	2000–4500	35.8	340	43	3	80	93–150
High density Polyethylene, PE-LD	10–20	6500–8500	11.6	100–200	375	5–10	65	120–177
Linear low density polyethylene, PE-LLD	15.5–18.5	200	7–135	150–900	200	6–13	–	104–170
Ionomer	25–35	6000	24–35	20–40	150	–	–	107–150
Ethylene/vinyl acetate, EVAC	40–60	12500	14–21	40–200	45	2–10	55–75	66–177
Ethylene/vinyl alcohol, EVAL	1000	0.5	8–12	400–600	–	1–2	90	177–205

Polyamide, PA	300–400	50–75	81	15–30	50–60	1.5	88	120–177
Poly(ethylene terephthalate) PET	15–20	100–150	159	20–100	100	2	88	135–177
Polystyrene, PS	70–150	4500–6000	45.1	2–15	59	1	92	121–177

3. Intelligent packaging in meat industry

Intelligent packaging can be defined as "systems that monitor the condition of packaged foods to give information about the quality of the packaged food during transport and storage". An intelligent packaging system contains smart devices which are small, inexpensive labels or tags that are capable of acquiring, storing, and transferring information about the functions and properties of the packaged food. The most commonly used smart devices in intelligent packaging of meat and meat products are summarized in Table 2 and 3.

3.1. Barcode

A barcode is an optical machine-readable symbol relating to the object to which it is attached. The first commercialized barcode was the UPC (Universal Product Code) introduced in the 1970s that has now become ubiquitous in grocery stores for facilitating inventory control, stock reordering, and checkout. The UPC barcode is a linear symbology consisting of a pattern of bars and spaces to represent 12 digits of data containing limited information such as manufacturer identification number and item number. To address the growing demand for encoding more data in a smaller space, new families of barcode symbologies such as Reduced Space Symbology (RSS), two-dimensional (e.g. PDF 417, Aztec code), Composite Symbology (combining a 2-D barcode such as PDF 417 with a linear barcode such as UPC) and GS1 DataBar Family have been introduced. Information including food packing date, batch/lot number, package weight, nutritional information, cooking instructions and the Web site address of food manufacturer can be encoded in the barcodes and they are even readable by smartphones; providing great convenience for both retailers and consumers. Barcodes are also good devices to identify the origin of food products and are widely used in meat and meat product packaging. In Australia, almost all meat and meat products in the retail market are sold with a barcode.

3.2. Radio frequency identification (RFID) tags

RFID technology is a form of electronic information-based intelligent packaging. Compared with barcodes, the RFID tag is a more advanced data carrier for product identification with several unique characteristics, such as significantly larger data storage capacity (up to 1 MB for high-end RFID tags), non-contact, non-line-of-sight ability in gathering real-time data, and can penetrate non-metallic materials for rapid and automatic multiple product identification. Nevertheless, the RFID tag is not considered as a replacement for the barcode, mainly because of its relatively higher cost and need for a more powerful electronic information network. It is anticipated that both RFID and barcode data carriers will continue to be used either alone or in combination, depending on the situation. RFID tags have the potential to be combined with temperature, moisture and/or chemical sensors, thereby giving the ability to trace environmental conditions within the supply chain. RFID can improve the movement of existing and new information associated with the product and its supply chain, from farming through to distribution, storage and retail. In addition, RFID tags have the potential to include consumer-specific information, such as cooking instructions. Advantages of RFID systems include increased quality control, improved inventory management (e.g. through stock rotation and shelf life algorithms), reduced product recalls, security and anti-counterfeiting.

Table 2. Examples of smart devices used in intelligent packaging and their principle of operation (Modified from Hurme et al., 2002)

Smart devices	Principle/reagents	Information given	Application
Barcodes	Symbology	Product and manufacturer information	Product identification, facilitating inventory control, stock reordering, and checkout
Radio frequency identification tags	Radio waves	Product and manufacturer information	Product identification, supply chain management, asset tracking, security control
Time–temperature Indicators	Mechanical, chemical, enzymatic, microbiological	Storage conditions	Foods stored under chilled and frozen conditions
Gas indicators	Redox dyes, pH dyes, Enzymes	Storage conditions, package leak	Foods stored in packages with required gas composition
Freshness indicators (e.g. Microbial growth)	pH dyes; Dyes reacting with (non-) volatile metabolites	Microbial quality of food (i.e. spoilage)	Perishable foods such as meat, fish and poultry

Pathogen indicators	Various chemical and immunochemical methods reacting with Toxins	Specific pathogenic bacteria such as *E. coli* O157	Perishable foods such as meat, fish and poultry

Table 3. Commercial intelligent packaging devices (Modified from Crossin et al., 2015)

Tradename / trademark	**Developer**	**Description**
OxySense	OxySense, USA	Biosensor
Ageless Eye®	Mitsubishi Gas Chemical Co. Japan	Integrity indicator (gas)
Tell-Tab	IMPAK, USA	Integrity indicator (gas)
O2Sense	Freshpoint, Switzerland	Integrity indicator (gas)
Timestrip®	Timestrip Ltd. USA	Integrity indicator (time)
Novas®	Insignia Technologies Ltd. Scotland	Integrity indicator (time)
Best-by®	Freshpoint, Switzerland	Integrity indicator (time)
3M Monitor Mark®	3M, USA	Time-temperature indicator (fatty acid ester)
VITSAB® TTI	VITSAB, Sweden	Time-temperature indicator (enzymatic)
Fresh-Check®	Lifelines Technology Inc., USA	Time-temperature indicator (polymerization)
Keep-it®	Keep-it Technologies, Norway	Time-temperature indicator (chemical)
OnVu®	Freshpoint and Ciba, Switzerland	Time-temperature indicator (photochemical)
TopCryo®	TRACEO, France	Time-temperature indicator (microbiological)
FreshCode®	Varcode Ltd. Israel	Time-temperature indicator (barcode)
Tempix®	Tempix AB, Sweden	Time-temperature indicator (barcode)
Raflatac	VIT and UPM, UK	Freshness indicator (colorimetric)
Easy2log®	CAEN RFID Srl, Italy	RFID
CS8304	Convergence Systems Ltd. Hong Kong	RFID
TempTRIP	TempTRIP LLC, USA	RFID
Intelligent box	Mondi PLC, Austria	RFID

3.3. Indicators

Indicators are a form of qualitative intelligent packaging that communicates the quality and/ or state of a product during the food chain. These can include time-temperature indicators (TTIs), integrity indicators and freshness indicators.

3.3.1. Time-temperature indicators

TTIs are typically labels which affix to the outside of a food pack, but indicators can also be applied directly to the food. TTI's serve as a proxy for an indication of bacterial activity, and thus can provide indirect information relating to product quality. TTIs work through mechanical, chemical, electrochemical, enzymatic or microbiological changes with time and temperature. These changes are typically indicated visually through deformation of a material, or a change/movement in colour. A key advantage of TTI's is that it allows products to be managed based on remaining shelf life, rather than first-in first-out, thereby reducing waste. In addition, TTI's are low cost, rendering them suitable for individual retail packs. For example, a Vitsab Checkpoint® TTI label is based on a colour change resulting from the controlled enzymatic hydrolysis of a lipid substrate. The TTI can be activated by applying gentle pressure on the "window" to break the seal between the enzyme and substrate mini pouches. A good mixing is recognized by a homogenous green color in the "window". When the dot is green, this represents the packaged foods are under perfect shipping and storage conditions. If the dot is yellow to light orange the product has not been compromised by time/temperature exposure.

3.3.2. Integrity indicators

Integrity indicators are small devices in the form of a package label or printed on packaging films that respond to the changes of a gas composition, thereby providing monitoring the quality, safety and integrity of packaged food products. Typically, a gas indicator also induces a color change to reflect the gas composition changes. Integrity indicators range in complexity from simply communicating how long a product has been opened, detecting leaks over the supply chain, to indicating the amount of ingress of a particular gas into a product at a point in time. Stakeholder needs determines the level of sophistication of the indicator and the nature of the communication. For instance if a consumer only needs to know how long an item has been open, a colour label activated on breaking of a product seal suffices. If the nature of the gas interactions after opening or in the case of a leak is required, a range of colour indicators such as redox dyes or tablets, convey these interactions most often in regard to oxygen content.

3.3.3. Freshness indicators

Freshness indicators are devices directly indicating the deterioration or loss of freshness of packaged goods. The development of freshness indicators is based on established knowledge of quality indicating metabolites specifically associated with the type of meat product, spoilage flora, packaging type and storage conditions. The major quality-indicating metabolites or chemicals representing meat freshness are glucose, organic acids (e.g. lactic acid), ethanol, volatile nitrogen compounds, biogenic amines (e.g. tyramine, cadaverine, putrescine, histamine), carbon dioxide, ATP degradation products and sulphuric compounds. Most of the freshness indicators change colour due to the presence of these metabolites or chemicals during spoilage.

3.4. Sensors

A sensor is a device which can provide signal(s) relating to the detection or measurement of a physical or chemical property. Most sensor systems require a receptor, which translates a detection or measurement into a signal, and a transducer, which reads this signal, which can then be analysed to produce a quantitative value, which can be stored in some instances. Types of sensors include gas sensors, fluoresence-based oxygen sensors and biosensors.

Gas sensors are often used to detect gas levels (either ambient or generated) in MAP systems. Recent advances in gas sensor technologies include non-destructive optical systems, used to detect gases produced from microbial activity (e.g. hydrogen sulphide, amines). Other research has focussed on utilising nanomaterials within packaging to enable gas detection. Fluorescence-based oxygen sensors provide a visual indication of the presence of oxygen. They are typically dies, incorporated into a polymer film matrix. Package biosensors to detect the contamination by pathogenic microorganisms of meat and meat products have also been developed. These devices consist of a bioreceptor that recognizes a target analyte and a transducer that converts biochemical signals into a quantifiable electrical response. Bioreceptors are organic or biological materials such as an enzyme, antigen, microbe, hormone, or nucleic acid, while transducers include electrochemical, optical and calorimetric, depending on the system. The interaction can occur through the use of antibodies. An example of a biosensor was the Food Sentinel system, which rendered a barcode unreadable by the presence of certain bacteria (Kerry et al., 2006). The pathogen indicators/sensors also change color in the food package to warn consumers/retailers that food must not be consumed.

4. Active packaging

Active packaging is an innovative packaging system/technology that allows the product and its environment to interact to extend the shelf life and/or to ensure food microbial safety, while maintaining the quality of the packed food. Active packaging generally describes any packaging system that protects food from contamination or degradation by creating a barrier to outside conditions while interacting with the internal environment to control the atmosphere within the package. The packaging absorbs food-related chemicals from the food or the environment within the packaging surrounding the food; or it releases substances into the food or the environment surrounding the food such as preservatives, antioxidants, and flavourings. The "releasing active materials and articles" are those designed to deliberately incorporate components that would release substances into or onto the packaged food or the environment surrounding the food; and "released active substances" are those intended to be released from releasing active materials and articles into or onto the packaged food or the environment surrounding the food and fulfilling a purpose in the food. Commercially available active packaging devices are given in Table 4.

4.1. Antimicrobial packaging

Antimicrobial active packaging is one of the most important concepts in active packaging because meat provides excellent nutrients for the growth of microorganism. Spoilage microorganisms including bacteria, yeast and molds, and pathogenic micrograms, specifically *Salmonella spp., S. aureus, L. monocytogenes, C. perfringens, C. botulinum,* and *E. coli O157:H7* are the major concerns leading to quality deterioration and food safety issues in meat. The aims of using antimicrobial active packaging are to extend shelf-life and to ensure food safety of meat and meat products. Antimicrobial active packaging can take several forms, including addition of sachets or pads containing volatile antimicrobial agents into packages, incorporation of volatile and non-volatile antimicrobial agents directly into polymers, coating or adsorbing antimicrobials onto polymer surfaces, immobilization of antimicrobials to polymers by ionic or covalent linkages, and use of polymers that are inherently antimicrobial. Antimicrobial additives react with microorganisms, causing a count reduction or inhibition (Lee, 2010). The additives used can be broadly classified into organic compounds and inorganic compounds. Organic additives used for direct incorporation into packaging films include organic acids and their salts (e.g. acetic acid, benzoic acid, potassium sorbate), fatty acids, plant extracts (including essential oils from herbs), peptides and antibiotics. Inorganic additives include metals (e.g. silver, zirconium), nitrites and sulphites and salts.

Table 4. Commercially available active packaging devices (Modified from Crossin et al., 2015)

Tradename / trademark	Developer	Description
FreshPax®	Multisorb Technologies Inc. USA	Oxygen scavenging / CO2 generating sachet
Ageless®	Mitsubishi Gas Chemical Co. Japan	Oxygen scavenging / CO2 generating sachet
OxyGuard®	Clariant Ltd. Switzerland	Oxygen scavenging Sachet
OxyCatch®	Kyodo Printing Company Ltd. Japan	Oxygen scavenging sachet
ATCO®	Emco Packaging Systems, UK and Standa Industrie, France	Oxygen scavenging sachet
Oxysorb	Pillsbury Co., USA	Oxygen scavenging sachet
Cryovac® OS2000	Sealed Air Corporation, USA	UV-activated oxygen scavenging film
Enzyme-based	Bioka Ltd. Finland	Oxygen scavenging film
Shelfplus® O2	Albis Plastic GmbH, Germany	Oxygen scavenging masterbatch
OxyRx®	Mullinix Packages Inc. USA	Oxygen scavenging container for high temperatures
OMAC®	Mitsubishi Gas Chemical Co. Japan	Oxygen scavenging film for high temperatures
Linpac	Linpac Packaging Ltd. UK	Moisture tray
TenderPac®	SEALPAC,	Dual compartment system
Dri-Loc®	Sealed Air Corporation, USA	Moisture pad
MeatGuard	McAirlaid Inc. Germany	Moisture pad
CO2® Fresh pads	CO2 Technologies, USA	CO2 emitting pads
UltraZap® Xtenda Pak pads	Paper Pak Industries, USA	CO2 emitting and antimicrobial pads
SUPERFRESH	Vartdal Plastindustri AS	Box system with CO2 emitter
Nor® Absorbit	Mondi Group, UK	Microwavable film
MoistCatch	Kyodo Printing Co., Ltd. Japan	Moisture and outgassing scavenger film
AgIon®	AgION Technologies LLC, USA	Antimicrobial substances
Biomaster®	Addmaster Limited, UK	Antimicrobial substances trays and films
Irgaguard®	BASF, Germany	Antimicrobial substances
Surfacine®	Surfacine Development Company LLC, USA	Antimicrobial substances
IonPure®	Solid Spot LLC, USA	Antimicrobial substances
Bactiblock®	NanoBioMatters, Spain	Antimicrobial substances
Nisaplin and Novasin	Integrated Ingredients, USA	Antimicrobial
SANICO®	Laboritories STANDA, France	Antifungal coating
Wasaouro®	Mitsubishi-Kagaku Foods Corp. Japan	Antifungal/ bacterial sheets, labels and films
FreshCase®	Bemis Company Inc. USA	Film that activates red colour in meat
Sira-Crisp®	Sirane Ltd. UK	Microwave susceptor
SmarthPouch®	VacPac Inc.USA	Microwave susceptor

4.2. Antioxidant packaging

The other class of directly-incorporated active packaging additives is antioxidants. These include substances such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), rosemary extract and α-tocopherol. These additives act by reacting with free-radicals, including oxides, which can detrimentally affect colour and odour.

4.3. Oxygen-scavenging packaging

High levels of oxygen present in meat packaging can facilitate microbial growth, lipid oxidation, development of off flavours and off odours, colour changes and nutritional losses. Therefore, control of oxygen levels in meat packaging is important to limit the rate of such deteriorative and spoilage reactions. Antioxidant active packaging can be used as a means of improving product quality and extending shelf life of meat and meat product through controlling the level of oxygen.e.g. iron powder, ascorbic acid.

4.4. Carbon dioxide emitting/generating packaging

CO2 has inhibitory activity against a range of aerobic bacteria and fungi, as well as direct antimicrobial effect, resulting in an increased lag phase and generation time during the logarithmic phase of microbial growth. For most applications in meat and poultry preservation, high CO2 levels (10–80%) are desirable because these high levels inhibit surface microbial growth; thereby extending shelf-life. The inhibitory action of CO_2 has differential effects on different microorganisms. Whereas aerobic bacteria such as *Pseudomonas* can be inhibited by moderate to high levels of CO_2 (10–20%), lactic acid bacteria can be stimulated by CO_2. Furthermore, pathogens such as *C. perfringens, C. botulinum and L. monocytogenes* are minimally affected by CO_2 levels lower than 50%. e.g. bicarbonate.

4.5. Moisture absorbers

A major cause of food spoilage is excess moisture. Soaking up moisture by using various absorbers or desiccants is very effective at maintaining food quality and extending shelf life by inhibiting microbial growth and moisture related degradation of texture and flavor (Scetar et al., 2010). In addition to moisture absorber sachets for humidity control in packaged dried foods, several companies manufacture moisture drip absorbent pads, sheets and blankets or liquid water control in high a_w foods such as meats, fish, poultry, fruit and vegetables. Basically they consist of two layers of a microporous non-woven plastic film, such as PE or PP, between which is placed a superabsorbent polymer that is capable of absorbing up to 500 times its own weight with water. Typical superabsorbent polymers include polyacrylate salts, carboxymethyl cellulose (CMC) and starch copolymers, which have a very strong affinity for water (Reynolds, 2007). Moisture drip absorber pads are commonly placed under packaged fresh meats, fish and poultry to absorb unsightly tissue drip exudate. Commercial moisture absorber sheets, blankets and trays include Toppan Sheet™ (Toppan Printing Co. Ltd, Japan), Thermarite™ (Thermarite Pty Ltd, Australia), Luquasorb™ (BASF, Germany) and Fresh-R-Pax™ (Maxwell Chase, Inc., Douglasville, GA, USA).

5. Aseptic packaging

Aseptic packaging of foods can be defined as a process where a pre-sterilized food product is filled and hermetically sealed in sterile packaging materials under an aseptic environment without reheating for sterilization. Aseptic processing requires the following items:

- sterilization of the products before filling
- sterilization of the packaging materials or containers and closures before filling
- sterilization of aseptic installations before operation – UHT unit, lines for products, sterile air and gases, filler and relevant machine zones
- maintaining sterility in the total system during operation – sterilization of all media entering the system, air, gases, sterile water
- production of hermetic packages.

Aseptic processing and packaging systems are integrated operations where the packaging step relies on the processor to provide a quality sterile product. Presterilization of food products consists of heating the food to the desired UHT temperature, maintaining this temperature for a predetermined time period to achieve sterility. The food is then cooled to ambient temperature or an elevated temperature to the desired viscosity for filling. Indirect heating methods for liquids with particulates include tube-type heat exchangers, scrape-type heat exchangers, rotaholders, ultra-high-pressure sterilization and microwave sterilization. Various methods for the sterilization of packaging materials are currently used in aseptic packaging systems. These include dry heat, saturated steam, superheated steam, UV light and ozone, hydrogen peroxide, pulsed light and ethylene. An aseptic packaging technique employing the form-fill-seal system relies on the temperatures reached by thermoplastic resin during the co-extrusion process used to produce the multilayer packaging material to produce a sterile product contact surface.

While the main form of aseptic packaging is the carton and is typically composed of paper (70%), polyethylene (LDPE) (24%) and aluminium (6%) with a tight polyethylene inside layer, pouches, cups, trays and plastic cans also be aseptically packaged. The paper component of the package provides stiffness, strength and the 'brick'-like shape of the package. Polyethylene is used on both the outer surface (printing surface) and the innermost layer of the package, forming a tight seal. An ultra-thin layer of aluminium foil provides a barrier against light and oxygen eliminates the need for refrigeration and prevents spoilage without the use of preservatives. The Tetra Wedge Aseptic (TWA) microwaveable 200 S pack launched by Tetra Pak in 2005 was the world's first microwaveable aseptic packaging. The innovative package, which uses polyethylene terephthalic silicon oxide (PET SiOx) as an oxygen barrier, is designed to ensure product safety and integrity as well as original flavour, colour and texture for 6 months without the need for refrigeration or preservatives. The distinctive new shape of the TWA microwaveable 200 S offers the benefit of even heating, easy handling and accurate pouring over conventional stand-up plastic pouches. Aseptically packaged, ready-to-serve meals are one of the newest aseptic technologies to appear on the market. Vetetee Rice (Japan) launched its Dine-In range of cooked rice in shelf-stable microwaveable plastic trays, sealed with a clear plastic lid.

6. Biodegradable packaging for meat industry

Table 6. Some commercially available biodegradable packaging for meat and meat products (Fang et al., 2015)

Products and manufacturer	Description
Back 2 Earth, Ridgeland, SC, USA	Meat trays made completely from wheat stalk and are GMO- and gluten-free.
BASF Co., Florham Park, New Jersey, USA	A new foaming grade of Ecovio biopolymers. Blends of BASF's petrochemical-basedEcoflex biodegradable resin with PLA.
BioMass Packaging™, Richmond, CA, USA	Foam trays made from Ingeo®
Bodin Industries, France	Foam trays made from PLA resin, and used to package meat or fish at the FiniperSpA super-market chain in Italy and organic chicken or duck.

BuyGreen, Irvine, CA, USA	Biodegradable trays made from corn polymers, starches and complementary ingredients to create a blend that is 100% biodegradable and microwave and freezer safe.
Clear Lam Packaging, Inc., Elk Grove Village, IL, USA	Made from Ingeo™ biopolymer to package a variety of meats, cheeses, pastas, egg rolls and other perishable food items.
CoopboxSpA, Reggio Emilia, Italy	The first foam PLA trays, called Naturalbox, in 2005 for meat, fish, or poultry.
Cryovac® Food Packaging Systems, SC, USA	NatureTRAY™, foam trays made from Ingeo™ and used to package meats, fish, poultry, and produce. Fully moisture resistant.
Dyne-A-Pak Inc., Laval, QC, Canada	Use Ingeo™ biopolymer (PLA) supplied by NatureWorks LLC with lightweight and efficiency of a foam packaging for meat, produce and deli.

6.3. Biodegradable packaging

Biodegradable packaging materials are defined as materials derived primarily from renewable sources, such as replenishable agricultural feedstocks, animal sources, marine food processing industry wastes, or microbial sources, and can break down to produce environmentally friendly products such as carbon dioxide, water, and quality compost. Biodegradation is the process by which carbon-containing chemical compounds are decomposed in the presence of enzymes secreted by living organisms, and requires appropriate temperature, humidity and type of microbes for a rapid degradation process. There are currently a range of commercially available biodegradable containers for meat and meat products. Among them, IngeoTM biopolymer by NatureWorks LLC. (Blair, Nebraska, USA) is mostly used to make foam trays. IngeoTM biopolymer uses dextrose (sugar) from corn as the primary feedstock (PLA), but can be made from any abundantly available sugar. Some commercially available biodegradable packaging for meat and meat products are presented in Table 6.

7. Conclusions

Modern meat packaging should serve as an efficient tool for maintaining quality and safety, as well as increasing product value, promoting sales and imparting information. Factors including price, safety, size of packaging and recyclability are most important, whereas design, convenience and utility must also be taken into account. Therefore, selection of appropriate packaging materials, packaging methods/conditions, and storage environments are the key to obtaining high quality packaged meat products. We can imagine that simple traditional packing will be replaced with multi-functional packaging, such as a packaging with biodegradable, active and intelligent functions. To develop successful meat packaging systems, key product characteristics affecting stability, environmental conditions, and consumer's packaging expectations must all be taken into consideration. A sustainable packaging solution can be achieved only if it is socially responsible, economically viable, and environmentally sound.

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Chapter 4

Climate smart technologies for slaughterhouse management

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Introduction

The global growth in food production has managed to keep pace with the rapid rise in population. In this process, the agri-food systems became the primary user of land and water, polluter of water sources, source of about a quarter of all greenhouse gas emissions and cause of soil degradation affecting 33% of all arable land (FAO, 2015). Environmental image is a growing challenge and life-cycle assessment studies need to be undertaken to determine environmental impacts of a food production across an entire supply chain (farm to fork). Hotspots should be identified and efforts should be focused where they are most needed. It also allows impact reduction strategies to be analysed to ensure impacts are not simply shifted from one part of the life cycle to another. A wide range of impact indicators can be assessed, starting from the energy use to water and waste impacts. Therefore a transformation of the global food system that delivers healthy diets from green, sustainable food systems is urgently needed. Consumers also sensitised about the environmental issues associated with food production, thereby reduction in the waste of food.

The demand for animal-sourced food particularly in Asia has increased so sharply. Producing animal based foods require a very large share of land and water resources. In developed and emerging economies, animal based foods are now produced intensively in large-scale factory-like facilities. Worldwide roughly half of all cereals produced are now fed to farm animals. Though the intensive system has higher productivity, but has significant environmental impacts, particularly pollution of surface and ground water, higher risk of zoonotic diseases and consumes a large amount of cereals as feed. The water footprint of the animal-sourced food industry is estimated at 29% of the total water food print of agricultural production (Mekonnen & Hoekstra, 2012). There are a number of studies predicting that future growth in animal sourced food products will be limited by water scarcity. Greenhouse gas (GHG) emissions from the livestock sector estimated at 7.1 Gigatonnes per annum, some 15% of human induced emissions and half of all of those from agri-food systems (Herrero & Thornton, 2013). Feed production and processing and enteric fermentation of ruminants, contribute 45 and 39% of emissions respectively, with manure storage and processing another 10% (Gerber, Steinfeld, Henderson, Mottet, Oppio, Dijkman et al., 2013).

Meat production has tripled in the last 50 years. India has become the world's largest exporter of bovine meat. The meat production and consumption have greater impact on sustainability - economy, society and environment (Allievi et al., 2015). When an animal is slaughtered, only one-third it is harvested as meat and the rest comprise byproducts and waste. The byproducts (including organs, fat, skin, feet, abdominal and intestinal contents, bone and blood) of cattle, pigs and sheep represent 66.0, 52.0 and 68.0% of the live weight, respectively. Further, during slaughter operation, starting from lairage to meat production stages, huge quantities of wastes is generated. Therefore the efficient processing and utilization of byproducts and management is waste is essential to reduce the impact on environmental from emissions. Further, refrigeration of meats within the cold chain is also responsible for ozone depletion and global warming (Coulomb, 2008). This article discusses on various means of utilizing byproducts, disposal of wastes, conservation of various resources like energy and water.

Energy efficient meat production and processing

The amount of energy used in meat processing depends on numerous factors which includes structure dimensions, the applied production technology, the manufacturing capacity, (utilization rate, and the throughput volume), processes mechanization degree, Human labour share in the slaughterhouses (the amount of work performed manually) and the thermo-physical properties of the raw material. Specific energy consumption (SEC) is the energy consumption per product and can be used as an indicator of energy use and may indicate the need of implementation of energy conservation measurements (Barbut ,2002, Kiepper, 2003, and Smith, 2014, Elmagd et al., 2017).

Approximately 80–85% of total energy consumed by abattoirs is provided by thermal energy from the combustion of fuels in on-site boilers. Thermal energy is used to heat water for cleaning, scalding and rendering of byproducts. The remaining 15–20% of energy is provided by electricity, which is used for operating equipment in the slaughter and boning areas, by-product processing, and refrigeration and compressed air. Typical ranges for the energy consumption are

1200–4800 MJ per tonne of hot standard carcass weight. Energy requirements for slaughterhouses vary depending on the scale of processing equipment and the extent of by-product processing. Advanced processing plants use significant amounts of electricity for refrigeration, air conditioning, lighting, pumps, motors and other equipment items. Local, small-scale slaughterhouses in developing countries have less, if any, automated equipment and generally no refrigeration. Many of the steps around slaughter, hide removal, washing, trimming, boning and related procedures are carried out manually and so energy requirements are significantly less, however, human labour makes up for this.

Substantial energy savings can be made almost immediately with no capital investment, through simple efforts. Additional savings can be made through the use of more energy efficient equipment and heat recovery systems. Some key strategies are listed below:

- Implementing switch-off programs and installing sensors to turn-off or power-down lights and equipment when not in use
- Improving insulation on heating or cooling systems and pipe work etc.
- Insulating and covering scald tanks to prevent heat loss
- Recovering waste heat from effluent streams, vents, exhausts and compressors
- Recovering evaporative energy in the rendering process using multi-effect evaporators
- Maintaining a leak-free compressed air system
- Favouring more efficient equipment
- Improving maintenance to maximise energy efficiency of equipment
- Maintaining optimal combustion efficiencies on boilers
- Eliminating steam leaks

In addition to reducing a plant's demand for energy, there are opportunities for using more environmentally benign sources of energy. Opportunities include replacing fuel oil or coal with cleaner fuels, such as natural gas, electricity produced from renewable sources or co-generation of electricity and heat on site. For some plants it may also be feasible to recover methane from the anaerobic digestion of high strength effluent streams to supplement fuel supplies.

Efficient utilization of byproducts

Depending upon the potential market, non carcass material may be utilized as edible byproducts, pet food, animal feed pharmaceuticals, cosmetics and fertilizer. Efficient utilization of byproducts estimated to generate about 11.4% of the gross income from beef, and 7.5% of the income from pork. However, circumstances like inadequate quantity of materials, lack of markets, cost of processing etc do not always permit efficient byproduct recovery and utilization.

Waste management principles

Waste avoidance and reduction at source, waste recovery, reuse and recycling and waste treatment and disposal are the three important waste management principals. Waste conservation and dry collection of different waste components facilitates better and economic treatment and disposal of waste. Managing solid waste is usually more cost effective than treating and disposing of it as a part of waste water. Collection of gut contents and dung in a relatively dry form can considerably reduce the waste water pollutant loading and waste water treatment costs. Segregation of waste water to recover animal tissues from those of fecal matter and gut contents allows animal tissues recovered for rendering without contamination and down grading of rendering material. Similarly gut content and feces without animal tissues could be composted by simple techniques and free from odors and better utilized.

Blood is most commonly collected for inedible processing by allowing it to drain into a collection pit. Blood loss from the carcass is also observed at hide pulling, brisket cutting and head removal which can be collected by dry cleaning. The most popular method to produce blood meal involves coagulating the blood proteins by steam injection, centrifuging the coagulum from the aqueous fraction, and then drying the coagulum. Temperature of 90-95 ^{0}C is optimal for coagulation. Ageing of blood improves coagulation. Yield of dried blood is about 12 to 15g per kilogram of dressed carcass weight in ruminants. Dry cleaning methods should be employed to collect meat and fat trimmings and fine debris from carcass saws. Gratings and perforated baskets in floor drains are normally used to prevent large pieces from entering the waste water.

Pollution prevention and wastewater flow reduction: A key element in the design of a wastewater treatment and disposal system is to first give consideration to all reasonable means to reduce wastewater volume. This can usually be achieved through fairly simple and low-cost practices and techniques that are available to most slaughter and poultry processing facilities regardless of size. The cost associated with these practices and techniques may be more than offset by savings in capital and operating costs associated with end of pipe treatment.

Table 1. National Standards for Slaughterhouse and Meat Processing Effluents

	Limit not to exceed mg/l		
Category	**BOD**	**TSS**	**Oil and Grease**
Slaughterhouse			
Above 70 TLWK	100	100	10
70 TLWK and below	500	---	---
Meat Processing			
Frozen meat	30	50	10
Raw meat from SH	30	50	10
Raw meat from other sources	Disposal via screen and septic tank		

BOD: Biological oxygen demand 5 days at 20^0C TSS: Total suspended solids

TLWK: Tonnes live-weight killed. *Source: COINDS/ 38/1992, CPCB, N. Delhi.*

Conducting water auditing of the plant will enable to take necessary measures for reduced water usage. The first step is to analyse water use patterns carefully, by installing water meters and regularly recording water consumption. The next step is to undertake a survey of all process area and ancillary operations to identify wasteful practices. Once water use for essential operations has been optimised, water reuse can be considered.

Some measures reported for pollution prevention and waste water reduction include:

1. Maximizing the segregation of blood and water by designing suitable blood collection facilities.
2. Reuse of relatively clean wastewater from cooling systems for washing livestock
3. Reuse of wastewater from slaughter floor, washbasins, knife and implement sterilizers and carcass washing for gut cutting and washing. Water may require screening to remove gross solids prior to reuse.
4. Boiler condensate that is not returned to the boiler may be used as make-up water for the scalding process.
5. Use of automated scalding chambers rather than scalding tanks for de-hairing.
6. Installation of automated controls to supply wash spray water to viscera section only when required.

7. Setting and maintaining minimum water flow rates for viscera table wash sprays.
8. Use of automated control systems to operate flow of water at knife sterilization and hand wash stations.
9. Use of dry dumping techniques for the processing of cattle paunches and pig stomachs instead of wet dumping techniques.
10. Use of air chillers for carcass cooling in poultry plants to reduce water use.

Using water-efficient equipment items, including spray nozzles, timers, automatic control switches, efficient wash systems, along with good housekeeping procedures such as repairing of water and steam leaks, will go a long way to reducing water use and wastewater generation. A saving in heating water and producing steam will have a dual saving effect in reducing energy. For small and medium-sized slaughterhouses, dry cleaning and selection of "cleaning friendly" smooth, washable and impermeable surfaces, as opposed to concrete floors, can help reduce water use.

Conclusion

As the meat production and consumption have greater impact on sustainability - economy, society and environment, the livestock as well as meat processing sector should take adequate measure in efficient utilization of land, soil, water, energy and other resources and also treatment and disposal of waste generated in the various points of value chain. Creating awareness among all the stakeholders of meat value chain from the farmers to consumers will go long way in conserving the natural resources and also reduce the environmental degradation. The adoption of and adherence to various quality control and environmental management standards both in primary production and in processing, coupled with cooperation, interaction and integration with all stakeholders along the meat value chain, including government and non-governmental agencies, entrepreneurs, industry associations, research bodies, technical associations and suppliers will help to ensure the production of wholesome meat products and will aid in the development of the greener supply chain.

Chapter 5

Animal physiology, stress and climate change

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1. Introduction

Stress is a reflex reaction revealed by the inability of an animal to cope with its environment which results in unfavourable consequences, ranging from discomfort to death. The behavioural and biological responses to a wide range of abiotic stressors such as social interactions, handling, farm practices, improper feeding, exposure to adverse environmental conditions, exercise, work and transport etc. Stress inducing stimuli are need not to be painful but modifies the psychological states, such as fear or anxiety also activate physiological responses. When an animal experience a threat or stress, it develops behavioural, autonomic, endocrine and immune response to restore the homeostasis.

The climate comprises of atmospheric variables such as temperature, precipitation, radiation and wind which reflects the cumulative of weather. Climate can be referred as a long term (over 30 years) average condition of the meteorological variables in a given region. It suggests that the representation of the climate in a particular region should contain an analysis of mean conditions such as polar, temperate and tropical, and climate based on geography, such as continental, marine and mountain. Therefore, climate change refers to a long period of oscillation in climate which recurs with some regularity. Efforts have been made in this chapter to describe the impacts of heat and cold stress and the various mechanisms by which

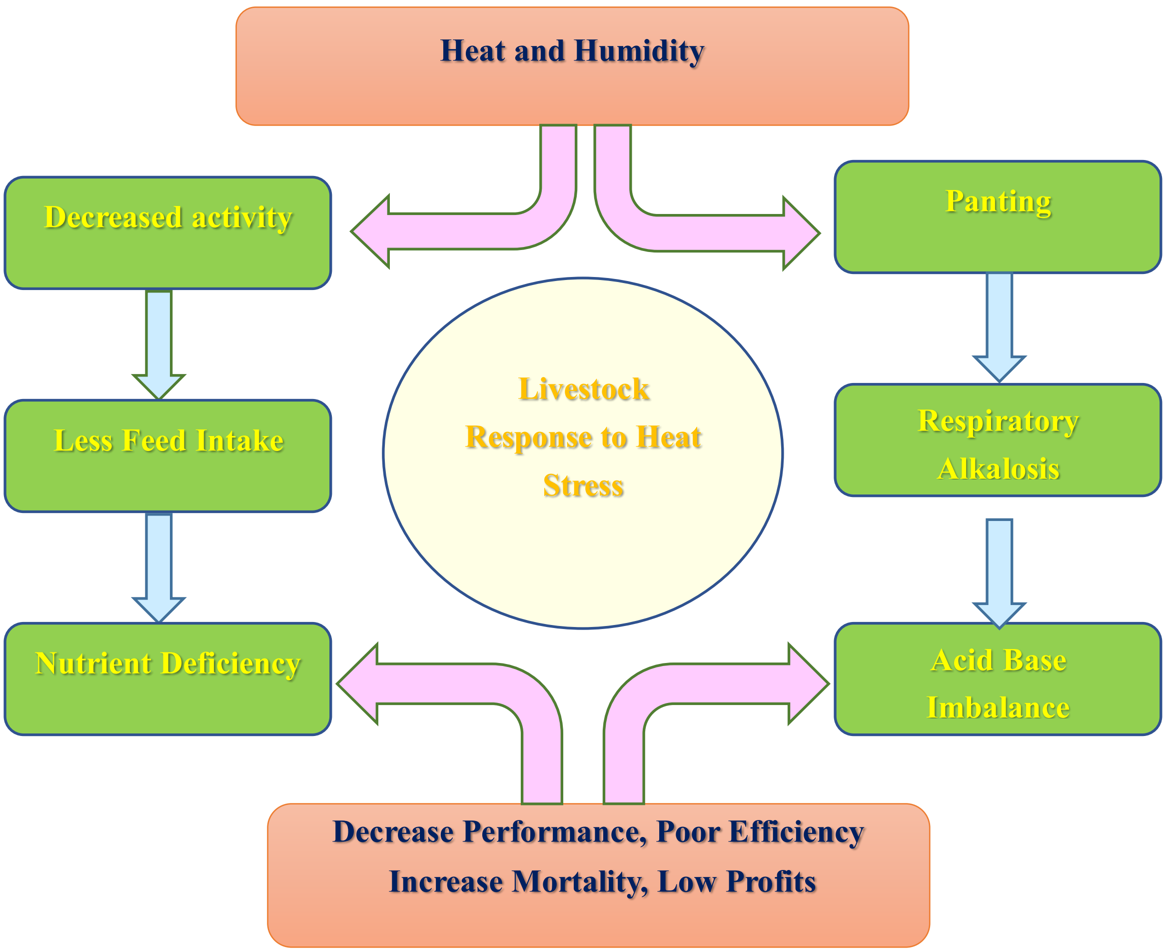
2. Boundaries of environmental temperatures

Animals are seeking for the optimum environment that provides a thermal comfort over wide range of ambient temperature. The temperature choice is associated with metabolic activity and achieves maximum efficiency within a specific range of core body temperature. Further, cell integrity is affected during a significant increase or decrease in core temperature above the acceptable physiological limits. The temperature seeking behaviour decreases the temperature difference between the environment and the animal by reducing the temperature gradient between internal and external compartments. This approach ensures minimum metabolic energy expenditure in animals to maintain normothermia. Temperature preference differs between species depending upon the time of day due to daily variations in their requirement for body heat production. The range of environmental temperature within which body temperature is maintained at constant with minimal effort from thermoregulatory mechanism is referred as thermoneutral zone (TNZ). TNZ varies with the age, species, breed, insulation, level of nutrition, earlier experience of temperature acclimation or acclimatization, production level, housing conditions, behavioural responses and time of the day. It is the temperature zone at which the animal may perform at its maximum. When the environmental temperature reaches the limits of the TNZ in opposite directions it approaches the lower and upper critical temperatures. The Ta below which the rate of heat production of a resting homeotherm increases to maintain thermal balance. Hence, the normal metabolic rate is inadequate to restore homeostasis and the body has to produce an extra heat as the environmental temperature falls. Here, the metabolic rate of the animal increase from the basal level to meet environmental demands for heat either by shivering or non-shivering thermogenesis. Further, when the Ta above upper critical temperatures, the rate of evaporative heat loss of a resting animal is increased to sustain thermal balance.

3. Effect of environmental factors on animal production

The environmental factors, ambient temperature, relatively humidity, radiant heat, precipitation, atmospheric pressure and wind velocity influence animal production. The exposure of animals to high or low environmental temperature and relatively humidity for long periods cause stress. Therefore, animals try to modify their physiological process to overcome the situation that responses are negatively influences the physiology of production and reproduction. The animals compensate within limits for variations in effective ambient temperature by altering feed intake, metabolism and heat dissipation mechanisms. There is a range of thermal conditions within which animals are able to maintain a relatively constant body temperature through behavioural and physiological responses. The increase in the environmental temperature leads to heat stress due to the inability of the animal to dissipate appropriate heat load. The increased environmental temperature causes many unfavourable effects on livestock species with reduction in milk yield and reproduction particularly in dairy cows. The extremes of climatic conditions impact negatively on livestock welfare, performance and health.

4. Impact of heat stress on livestock production and reproduction



Global CC is expected to alter temperature, precipitation, atmospheric carbon dioxide levels, and water availability in ways that will affect the productivity of crop and livestock systems. For livestock systems, CC could affect the costs and returns of production by altering the thermal environment of animals thereby affecting animal health, reproduction, and the efficiency by which livestock convert feed into retained products (especially meat and milk). Further, it is predicted that global warming is likely to increase temperature levels and the frequency of extreme temperatures – hotter daily maximums and more frequent or longer heat waves – which could adversely affect livestock production in the warm season.High ambient temperatures, solar radiation, and humidity are environmental stressing factors that affect animals.

Reproductive axis is one plane where stress effects are the most pronounced and have gross economic impact. Stress activates systems which influence reproduction at hypothalamus, pituitary or gonads levels. The reproductive axis is inhibited at all levels; steroidogenesis is directly inhibited at both ovaries and testes. The principle target is the GnRH neuron activity thus affecting the GnRH secretion into the hypophyseal portal blood. Stress can also affect the gonadotrophic cell responsiveness to GnRH. Glucocorticoids are critical to mediating inhibitory effect on reproduction. Environmental stresses affect the estrous behaviour, embryo production, birth weights of lambs, placental size, and function and foetal growth rate. Several factors affect the reproductive performance of farm animals, among which the physical environment and nutrition play a significant role. Most reproductive responses to environmental factors are coordinated at the brain level, where all external and internal inputs ultimately converge into a final common pathway that controls the secretion of gonadotrophin-releasing hormone (GnRH). In turn, this neurohormone controls the secretion of gonadotrophins, the pituitary hormones that determine the activity of the reproductive axis.

5. Measurement of heat stress in animals

The temperature humidity index (THI) is a simple method to determine the level of heat stress in animals. THI is a combination of ambient temperature (Ta) and relative humidity (RH) into a single value to estimate the degree of stress. The THI formulas vary from each location and also depend on the variables available to estimate it. THI is calculated based on Ta and RH according to Thom (1959) as follows: THI = 9/5 x [(Ta x 17.778) - (0.55 - (0.55 x RH/100) x (T-14.444)], value of THI < 72 indicates thermo-neutral conditions and THI 76 to 78.5 represents mild to moderate heat stress. Another, THI derived from a combination of wet and dry bulb air temperatures for a particular day and expressed in a formula as per McDowell et al. (1976), THI = 0.72 (W°C + D°C) + 40.6, where W°C = wet bulb and D°C = dry bulb. The THI values of 70 or less comfortable, 75-78 stressful, and values above 78 extreme distress. The THI in combination of the temperature and humidity using the following formula; THI = (Dry-Bulb Temperature °C) + (0.36 Dew Point Temperature °C) + 41.2). THI is exceeding 72 indicates mild stress, 80 designates as medium stress and above 90 signifies as severe heat stress in cattle.

6. Thermoregulation during cold and heat

The maintenance of core body temperature during cold when the environmental temperature drops below the lower critical temperature depends upon the ability to increase the metabolic rate. The increase in metabolic rate of small mammals is higher and proportionate to the three-fourth power of body weight (6 times) as that of basal metabolic rate. The hypothermia may cause cold injuries in the extremities such as the ears though the arterio-venous anastomoses provide some protection against frostbite. However, maintenance of homeothermy is more critical during hot environmental conditions than a cold. The heat tolerance capacity of the animals depends on the evaporative cooling mechanisms where the sweating species tolerate higher environmental temperatures than panting species. When the heat load becomes severe, animal may not able to regulate constant temperature and the body temperature increases and results in hyperthermia. The enhancement of hyperthermia results in failure of sweating and respiratory mechanisms and ultimately leads to a breakdown of thermoregulation.

7. Effects of heat and cold stress on metabolism

The metabolic heat is the primary source of heat accumulation in animals which is produced within the body for every biochemical process in relation with body function such as growth, lactation and pregnancy. The increase in metabolic heat is essential during cold to maintain body temperature while metabolic heat has to be dissipated from the body during warm periods. Animals that are well adapted to hot conditions consistently decrease heat production or increases heat loss mechanisms to maintain the homeothermy. The exposure to cold or heat stress negatively affects the performance of animals in terms of productivity and feed efficiency. The vulnerability of animals to clod stress differs highly amongst them depending upon their stage of life, production phase and breed. The energy demand increases with decreasing temperatures during winter to enhance resting heat production to sustain the body temperature by shivering or non-shivering thermogenesis. Therefore, thermal stress caused by the variations in environmental temperature above and below thermo-neutral condition results in decreased performance of animals. Heat stress decreases the feed intake which is an effort of animal to decrease the metabolic heat production.

8. Different adaptive mechanisms of livestock to heat stress

8.1. Behavioral and Morphological adaptability

When the animals are subjected to heat stress the animals try to alter its behaviour to adjust to the situation. The behaviour variables established to be playing a role for adaptation includes reduced standing, increased lying, increased drinking, reduced defecation, reduced urination, and decreased rumination behaviour. An adaptation is referred to means by which an animal makes it possible for it to live in a particular place and in a particular way. It may be a phenotype adaptation, like the size or shape of the animal's body, or the way in which its body works i.e. physiological adaptation. Or it may be the way the animal behaves. Each adaptation has been produced by evolution. A novel study by a team of scientists in Britain reported that average body size of a wild Soay sheep of Hirta (Scottish island) in the St Kilda archipelago has decreased by approximately 5% over the last 24 years. This is in contradiction to evolutionary theory which suggests that average size of wild sheep increases during process of evolution in colder environment and tend to be more likely to survive and reproduce than smaller ones. The reason for bringing down the size of Soay sheep was attributed to shorter and milder winters caused by global climate change. In the changing climate conditions, the weight gain by the lambs during early months of life was diminished as compared to few decades back when winters were colder. The lambs had to put more weight to survive under extreme cold for survival. The advantage of dark coloured coat of animals over lighter counterparts in colder environment is linked to conservation of solar energy and saving food energy for maintenance of homeothermy. The change in climate (warmer cold season) has been associated with the change in the proportion of light colored Soay sheep in total population. A study has revealed that dark colored Soay sheep have decreased over the past 20 years as the ambient temperature was increased.

8.2. Physiological adaptability

Normal fluctuations in physiological responses, i.e. respiration rate, pulse rate, rectal temperature and sweating rate vary with the changes in season in an effort to maintain normal body temperature independent of the fluctuation in environmental temperature. Hence these are considered important indices for comparative adaptability of different genotypes. Increased respiration rate is the first reaction when animals are exposed to environmental temperatures above the thermoneutral zone. This response ensures direct heat stimulation of the peripheral receptors, which transmit nervous impulses to the heat centre in the hypothalamus. The magnitude of physiological responses evoked by thermal stress and time required for their subsequent return to normalcy after removing the stress were considered useful indices for assessing the thermal ability of animals. Sweating in livestock is considered to be important in heat dissipation than respiratory evaporative cooling. The native animals were found to utilize cutaneous evaporative cooling relatively more than exotic animals during thermal stress at high ambient temperature. The environmental variables viz; ambient temperature relative humidity and wind velocity have been found to influence sweat gland structural dimensions and coat characteristics in sheep.

8.3. Neuron-endocrine response to stress in animals

Physiological responses of animals to stress activate endocrine, autonomic and CNS in a synergistic way depending on the degree of stress to sustain the homeostasis. Stress regulating systems varies among individuals depending upon their earlier experience, physiological status, genetic predisposition, the duration and intensity of stress. Therefore, stress triggers several neuroendocrine responses in animal which activates many hormonal axis and release of hormones that facilitate the adaptive and behavioural responses. These stress hormones prioritize the energy distribution for maintenance of muscular and neural functions, enhances the perception of the environment, increases the glucose level to brain, adjustments in cardiovascular and respiratory functions, modulation of immune responses and ultimately results in decreased productive and reproductive performance.

The environmental stressors activate sympathetic-adrenal-medullary (SAM) and the hypothalamic-pituitary-adrenal (HPA) axis. These axes act synergistically to elicit different stress responses in combination of interplay of adaptive responses of different organs and receptors to conquer extreme stress conditions. HPA axis is activated directly or indirectly by stress, drought and nutritional stress that enhances glucocorticoid secretion. The activation of the SAM axis ensures prompt activation of the autonomic nervous system for the secretion of catecholamines, adrenaline and noradrenaline. The adrenal and thyroid hormones play a significant role in thermoregulation and metabolic response of animals during stress. The stimulation of HPA axis increases the level of adrenocorticotropic hormone which in turn enhances the production of glucocorticoids, especially cortisol which is an important stress-relieving hormone. Cortisol regulates the behavioural and neuro-endocrine activities during stress which induce the hepatic gluconeogenesis and enhances the production of glucose from non-carbohydrate sources to maintain energy homeostasis and to restore the life sustaining activities.

8.4. Molecular and cellular mechanism of livestock adaptation

Genetic selection has been a traditional method to reduce effects of environment on livestock by development of animals that are genetically adapted to hot climates. Despite the strong knowledge base about the physiological aspects, the effects of heat stress at the cellular and genetic level are not clearly understood. It is the cellular/molecular level at which stress also has its deleterious effects. Thus, the adaptive response is observed at cellular level as well and an insight into the molecular/cellular mechanism of stress relieve is important. As a result of stress, there are an increased number of non-native conformational proteins with anomalous folding. Heat shock proteins, as we know, are evolutionary conserved and many of them act as regulator of protein folding and structural functions of proteins. There is presence of common environment specific response genes, making 18-38% of the genome. These genes induce expression of classical heat shock proteins, osmotic stress protectants, protein degradation enzyme etc.

Functional genomics research is providing new knowledge about the impact of heat stress on livestock production and reproduction. Using functional genomics to identify genes that are regulated up- or down during a stressful event can lead to the identification of animals that are genetically superior for coping with stress and toward the creation of therapeutic drugs and treatments that target affected genes. Given the complexity of the traits related to adaptation to tropical environments, the discovery of genes controlling these traits is a very difficult task. One obvious approach of identifying genes associated with acclimation to thermal stress is to utilize gene expression microarrays in models of thermal acclimation to identify changes in gene expression during acute and chronic thermal stress. Further, gene knockout models in single cells also allows for better delineation of the cellular metabolic machinery required to acclimate to thermal stress. With the development of molecular biotechnologies, new opportunities are available to characterize gene expression and identify key cellular responses to heat stress. These new tools enable to improve the accuracy and the efficiency of selection for heat tolerance. Epigenetic regulation of gene expression and thermal imprinting of the genome could also be an efficient method to improve thermal tolerance.

9. Conclusion

Among the environmental variables, heat stress seems to be the most detrimental factor affecting livestock production. Heat stress can cause a significant financial burden to livestock producers by decreasing milk and milk component production, meat production, decreasing reproductive efficiency, and adversely affecting livestock health. In addition, CC is seen as a major threat to the survival of many species, ecosystems and the sustainability of livestock production systems in many parts of the world. Livestock production is thought to be adversely affected by detrimental effects of extreme climatic conditions. Consequently, adaptation and mitigation of detrimental effects of extreme climates have played a major role in combating the climatic impact in livestock production. Infact the animals can adapt to the hot climate, nevertheless the response mechanisms are helpful for survival but are detrimental to performance. Hence formulating mitigation strategies incorporating all requirements of livestock is the hour of need to optimize productivity in livestock farms.

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Chapter 6

Climate change and animal welfare

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Global demand for livestock products is expected by double by 2050, mainly due to improvement in the worldwide standard of living. Meanwhile, climate change is a threat to livestock production because of the impact on quality of seed crops and forage, water availability, animal and milk production, livestock diseases, animal reproduction, and biodiversity. Climate is one of many factors with the potential to alter disease states and is expected to exert an overwhelming negative effect on the health of humans and animals. In addition, several studies suggested that the increase of temperature might reduce mortality and/or improve health and welfare related aspects in humans and livestock living in geographic areas with cold winters. The effect of climate change on animal may be either direct or indirect and may be due primarily to changes in environmental conditions, which include air temperature, relative humidity, precipitation, and frequency and magnitude of extreme events (i.e., heat waves, severe droughts, extreme precipitation events, and coastal floods). However, there is a very real risk that the altered climatic conditions will compromise animal health, welfare and productivity. The livestock sector therefore needs to adapt to changes in the climate. Firstly, we need to know how welfare will be affected. Animals may experience thermal stress due to direct effects of changes in temperature and precipitation levels and seasonal patterns. Additionally, there are other more indirect effects of climate change on animal welfare, such as changes in land use away from the production of livestock feedstuffs or changes in prevalence of disease and parasites. There are also changes in local and national policy with respect to livestock farming to consider.

Climate Change

The Earth's surface has been successively warmer over each of the last three decades compared to any preceding decade since 1850. Human activities are responsible (with a 95%–100% probability) for the recent global warming and the marked increase in global atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) to above preindustrial values. By sector, greenhouse gas pollution originates primarily from industry; agriculture, forestry and other land use (AFOLU); buildings; and transport. Livestock contribute both directly and indirectly to climate change. Enteric fermentation and manure associated emissions are direct, while production and transport of feed (including the fossil fuels used in manufacturing chemical fertilizers) and land use changes (such as conversion of forest to pasture and crop land) contribute indirectly. About 44% of the emissions generated by livestock are enteric fermentation (eructation in ruminants) and emitted from manure decomposition; 27% are in the form of CO_2 emitted during the production and transport of animal products and feed, and 29% are N_2O attributable to manure and fertilizer.

Animal Welfare

The term ‘animal welfare,’ in both the lay and scientific community, is often used to refer to a concept. In this context, positive animal welfare may be substituted with the term ‘well-being.’ ‘Animal welfare’ also refers to a measurable state in an animal which may be related to the adequacy of an animal’s ability to cope with its environment. Animal welfare is a branch of science which looks at these measurable states in almost all areas of our interaction with animals – agriculture, entertainment, companionship, research, and others. Animal welfare is becoming a greater and greater concern. Animal welfare is important to meat production because poor animal welfare is associated with poor animal production or health, and because consumers' concerns may influence market access. Throughout the world, animal welfare is the topic of legislation, retailer standards, and codes of practice. An animal has good welfare if it is in good health and feeling good, and the psychological component must not be ignored. Challenges to animal welfare differ between species and production systems. Concern about animal welfare is highest for intensive production but extensively housed animals also have welfare problems. Poor welfare is apparent in the animal's health, behavior, production, and physiology. Different welfare indicators detect specific challenges to animal welfare, rather than measuring the overall welfare. Maintaining high standards of animal welfare should be an integral part of a processing plant's overall meat quality and food safety program. In many plants, animal welfare audits are conducted by the quality assurance department that has responsibility for food safety, meat quality, and animal welfare. Animal welfare was identified as a priority when OIE Member Countries mandated the organisation to take the lead internationally on animal welfare and to elaborate standards and guidelines covering animal welfare practices. To date, the OIE has developed welfare standards both for terrestrial and aquatic animals. These encompass the transport of animals by land, sea, and air, the slaughter of animals, the killing of animals for disease control purposes. The next standards to be developed are on dairy cows and later hens and pig production systems, working animals as well as disaster management and risk reduction in relation to animal health and welfare and veterinary public health.

There is growing interest in understanding the interaction of climate change and animal production and it is motivating a significant amount of research. Animal welfare has been defined in several ways and using numerous criteria (biological function, behavioral ecology or emotional state). There is one approach that gathers all these aspects to an apparently simple definition of animal welfare, animals are healthy and they have what they want. This definition stresses the importance of good health and animal needs (either physical or emotional) to achieve good standards of welfare. Animal welfare is considered to be a necessary element of sustainable animal production. Increasingly, society demands that animal welfare be integrated into the concept of sustainable livestock production. A growing number of consumers demand ethical production systems and refuse to buy products if they are produced under morally unacceptable circumstances.

Temperature affects most of the critical factors for livestock production, such as water availability, animal production, reproduction and health. Forage quantity and quality are affected by a combination of increases in temperature, CO_2 and precipitation variation. Livestock diseases are mainly affected by an increase in temperature and precipitation variation. One of the major causes of decreased production in the dairy and beef industry is heat stress and significant economic losses have been related to this. The poultry industry may also be compromised by low production at temperatures higher than 30 ^{O}C. Heat stress on birds will reduce body weight gain, feed intake and carcass weight, and protein and muscle calorie content. Heat stress on hens will reduce reproduction efficiency and consequently egg production because of reduced feed intake and interruption of ovulation. Prolonged high temperature may affect metabolic rate, endocrine status, oxidative status), glucose, protein and lipid metabolism, liver functionality (reduced cholesterol and albumin) etc. Warm and humid conditions that cause heat stress can affect livestock mortality. Increases in temperature between 1 and 5^{O}C might induce high mortality in grazing cattle. Livestock and plants will be highly affected by climate change and biodiversity loss. These breeds and species cannot be replaced naturally; therefore, future work that studies the inherent genetic capabilities of different breeds and identifies those that can better adapt to climate conditions is vital. No matter what kind of livestock, and what kind of rearing system, sufficient drinking water is the most important factor for the animal's health and welfare, with watering location being equally important. This can be problematic if regional water shortages occur as part of climate change. In addition, nutritional imbalance and deficiencies may exacerbate the effects of heat stress, so it is necessary to provide the animals with nutritionally balanced diet.

Mitigation strategies and negative animal welfare

With severe and widespread destructive effects, warming of the planet threatens ecological systems, peoples' livelihoods, and species survival. To reduce the contribution of emissions attributable to animal agriculture, a number of mitigation strategies involving changes to farming practices have been proposed. Although this is an important and timely goal, and many of the proposed solutions seem reasonable on the surface, mitigation strategies can have complex effects on people and animals in practice. While there has been occasional mention, in the global discussion on climate change there has generally been a dearth of attention paid to the animal welfare impacts of the proposed abatement options, and some of the suggested livestock management approaches would have severe and wide-ranging impacts on the animals. At the same time, in other arenas there is a growing international social movement afoot aimed at addressing animal welfare, the physical and psychological state of animals. There are many animal welfare issues associated with commercial farming practices, especially in industrial agricultural production systems, where animals are often confined indoors at high stocking densities. The conditions in which the animals are kept are a matter of serious deliberation in legislative, corporate, investment and trade organizations, among many others around the world.

The most promising approach for reducing methane emissions from livestock is by improving the productivity and efficiency of livestock production, through better nutrition and genetics. Greater efficiency means that a larger portion of the energy in the animals' feed is directed toward the creation of useful products (milk, meat, draught power), so that methane emissions per unit product are reduced. The trend towards high performing animals and towards monogastrics and poultry in particular, are valuable in this context as they reduce methane per unit of product. The increase in production efficiency also leads to a reduction in the size of the herd required to produce a given level of product. Because many developing countries are striving to increase production from ruminant animals (primarily milk and meat), improvements in production efficiency are urgently needed for these goals to be realized without increasing herd sizes and corresponding methane emissions. However, by far, the most substantial emissions reductions can come through adaptations in current systems rather than requiring a shift to industrialized systems. This is important from an animal welfare perspective. While there can be negative animal welfare impacts in all production systems, industrialized production has inherently problematic effects on billions of animals globally. Thus, it is important that there is significant alignment in both animal welfare and climate goals.

Conclusion

Major scientific studies have shown that climate change (i.e. increasing average temperature of the Earth) is likely. With the increasing mean global temperature; the most direct effect on animals is heat stress, which has been proven to have a variety of negative effects on animal health, welfare and productivity. Different potential measures could be used in future to alleviate the increased heat stress. Some of these measures are mere adaptations or improvements of current engineering solutions. However, facing the complex challenges of global warming and climate change will probably require novel solutions, including new designs based on solid engineering judgment, development of new engineering standards and codes to guide designs, the exploration of new and superior building materials, the need for better energy management, and the development of substantially more “intelligent”control systems that will balance changing exterior disturbances, interior building loads and demands to the biological needs of the occupants of the structures. Transport and lairage regulation may need to be reconsidered in light of the potential for extreme heat and cold climatic events. Recommendations and codes of practice for farmers, hauliers and other livestock keepers on how to cope with higher average temperatures and extreme events should be drawn up. Government policies that promote the intensification of livestock housing and production or promote changes in land use away grassland or the production of livestock feeds should be considered from an animal welfare perspective.

Chapter 7

Climate change and its impact on livestock with special reference to infectious diseases

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Introduction

The climate on our planet has been constantly changing and in coming years it may pose indomitable challenges and serious public health threats to every form of life on this earth. Special report on global warming warns that average global temperatures could breach the 1.5^{0}C level as early as 2030. The mean global temperature is expected to increase by another 1.8 to 5.8°C by the end of this century. The overall effects of climate change are likely to be long-standing and remain harmful in terms of the increased spread of diseases, heat-related deaths, and air pollution. Climate change-induced natural calamities quite often disrupt the natural ecosystems by providing more suitable environments for infectious diseases, allowing the disease-causing bacteria, viruses, and fungi to move into new domains. In short, climate change is strongly associated with fast-changing disease dynamics favouring the emergence and re-emergence of animal and communicable diseases, including zoonoses; increase in the vector population and disease spread to newer territories; increase in the diseases causing potential of infectious agents, and thereby, inflicting more harm to hosts in wildlife, domestic species, as well as humans; besides compromising their body defense due to enormous stress caused on account of extreme temperatures as well as loss of shelters and food. Climate change is also projected to be a “poverty multiplier” through food insecurity, higher food prices, income losses, lost livelihood opportunities, adverse health impacts, and population displacements (Times of India, 2018). While climate change is a global phenomenon, its negative impacts are more severely felt by poor people in developing countries, who rely heavily on the natural resource base for their livelihoods. Resource-poor communities in rural settings depend heavily for their survival on agriculture and livestock keeping that are amongst the most climate-sensitive economic sectors. Livestock production is likely to be adversely affected by climate change, as the competition for land, water, and food security would increase, making them the most indispensable (Thornton, 2010).

Importance of Livestock in Indian scenario

Livestock is considered as the "bank-on-hooves", which over time has proved itself as an important source of livelihoods and household income in rural segments of the country. India is bestowed with the highest number of livestock wealth (535.78 million) (20^{th} Livestock Census) and 58% out of its total 72% rural population (over 100 million) consider livestock farming as a central source of their livelihood (19^{th} Livestock Census). The livestock sector by providing food (milk, meat and eggs) and non-food (fibre, wool, skins, dung, urine) commodities to the people and contributing 28.6% of the value of agricultural output (DAHD&F Report 2017-18), has been playing an important role in the Indian economy.

Role of livestock sector in climate change

Global warming is closely associated with the emission of Greenhouse gases (GHG) and livestock supply chains. GHG are emanated primarily from feed production and processing (45% of the total), during digestion by cows (39%), and manure decomposition (10%). The remaining GHG production is attributable to the processing and transportation of animal products, which is estimated to be 7.1 gigatonnes (GT) of Carbon-di-oxide equivalent (CO_2-eq) per year, representing 14.5% of all the human-induced emissions. Cattle-raising has been estimated to contribute 65% of the livestock sector's total GHG emissions; beef and cattle milk production account for 41 and 19% emissions, while pig meat and, poultry meat-cum-eggs contribute 9% and 8% to the sector's emissions, respectively (FAO, 2013; 2014).

Climate change and infectious diseases

Climate is one of most important factors influencing the incidence of infectious diseases. In this era of globalization and land-use changes, it is highly unlikely that climatic changes exert an isolated effect on disease; rather the effect is likely dependent on the extent to which human and animals cope with or counter the trends of other disease modifying influences. Climate constrains the range of infectious diseases, while weather, which is impacted by climate, affects the timing and intensity of outbreaks (Epstein, 2001). Therefore, the two early manifestations of climate change in terms of disease pattern, particularly global warming, would be expansion in the geographic range and seasonality of disease, and the emergence of outbreaks occurring as a consequence of extreme weather events (Epstein, 2001).

When it comes to the role of climate change in disease ecology and pathogen evolution, there is a need to duly consider the collective host–pathogen–environment interplay. In a stable environment, a situation of relative evolutionary stasis, host–pathogen–environment complexes tend to become more entrenched, with location-bound pathogen traits selected for. Conversely, in a rapidly changing environment, it is pathogen opportunism and generalist type versatility that matters (FAO, 2012). Infectious agents that were restricted by seasonal weather patterns can invade new areas and find new susceptible species as the climate warms and/or the winters get milder. There is evidence that the increasing occurrence of tropical infectious diseases in the mid latitudes is linked to global warming (IAEA, 2010). Insect-borne diseases are now present in temperate areas where the vector insects were non-existent in the past (e.g. Trypanosomiasis, Anaplasmosis). Humans are also at an increased risk from insect-borne diseases such as malaria, dengue, and yellow fever (IAEA, 2010). The average temperature in the world has increased in the last few years compared to the previous century and is expected to continue rising if measures are not taken particularly by highly industrialized countries to reduce greenhouse gases emissions. Ironically, the countries that have contributed least to global warming– mainly the developing countries– are the most vulnerable to its impact, especially from diseases that higher temperatures can bring (Malik *et al*., 2012).

Climate variability's effect on infectious diseases is determined largely by the unique transmission cycle of each pathogen. Transmission cycles that require a vector or non-human host are more susceptible to external environmental influences than those diseases which include only the pathogen and human. Important environmental factors include temperature, precipitation and humidity. Several possible transmission components include pathogen (viral, bacterial, fungal, parasitic, rickettsial etc.), vector (mosquito, snail, ticks, lice, mites etc.), non-biological physical vehicle (water, soil etc.), non-human reservoir (mice, deer, bats etc.) and human host.

The overall outlook towards climate change as well as infectious diseases varies with different specializations. To detail, for clinicians who are concerned with the treatment of infected individuals, the clinical manifestation of the disease gains prime importance. Alternatively, microbiologists tend to classify infectious diseases by the defining characteristics of the microorganisms, such as viral or bacterial. For epidemiologists, the two characteristics of foremost importance are the method of transmission of the pathogen and its natural reservoir, since they are concerned primarily with controlling the spread of disease and preventing future outbreaks (Nelson, 2000). In this regard, this literature attempts to overview the climate change and its implications on animal health.

Potential impacts of climate change on varied fields of animal health and productivity

Climate change and general anthropogenic factors together alter both the farming and the natural landscapes and in the process impact the health of animals in multiple ways. Importantly, changes in host distribution, density and their availability to existing pathogens may translate in disease emergence in animals and at the animal-human interface. A pathogen may either find access to new territories and host landscapes, or turn more host aggressive in settings where the hosts have become more abundant and/or immune-compromised; or even perform a host 'species-jump', possibly in response to enhance host 'species-mixing' or contacts, which may results in the spill-over mechanism of infections. Geographic spread or invasion of the disease may entail a range expansion or, in case of saltation dispersal, kick-start a complete pathogen genetic remake. Climate change clearly plays a role in this regard, enhancing or decreasing the introduction and invasions of disease agents, even when primarily caused by other factors such as the demography of humans and animals, encroachment of the natural resource base, land use, agriculture, the greater mobility of people, and the enhanced trade and traffic volumes (FAO, 2012).

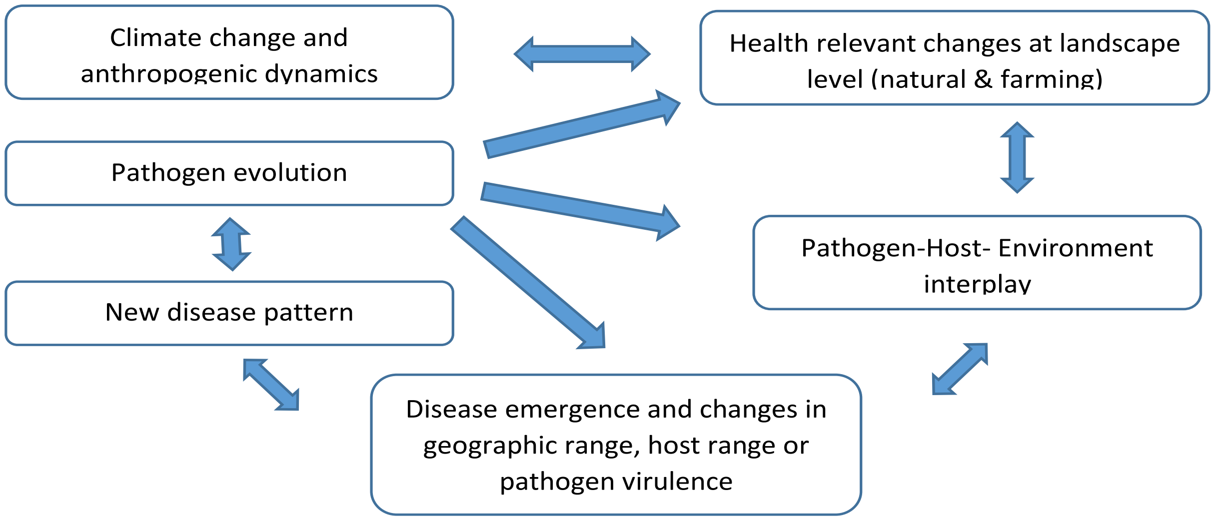

Fig.1. Effects of climate change on disease emergence, adopted from FAO (2012).

1. ***Microbial evolution and stress response***: Climate-induced changes in intrinsic factors may induce stress responses that make certain bacteria more resistant. Many bacterial agents have developed mechanisms that allow them to survive and even grow under unfavourable or 'stressful' conditions. Stress responses are encoded genetically and in many cases, initial exposure to a sub-lethal dose of a stressor will 'condition' the bacterial cell, allowing it to survive even harsher conditions provided by that stressor. This is well documented for the potential food-borne bacterium, *E. coli* O157:H7, wherein, the organism is able to survive an acid shock as low as pH 2.0, after previous exposure to pH 5.0 (Rodriguez-Romo and Yousef, 2005).
2. ***Pathogen emergence***: Climatic change can also impact the emergence or re-emergence of infectious disease agents. An emerging disease is one that has appeared in a population for the first time, or that may have existed previously but is rapidly increasing in incidence or geographic range (WHO, 2010). There are some general principles of pathogen emergence, which are associated with changes ecology and agriculture, technology and industry, globalization, human behaviour and demographics, epidemiological surveillance and microbial adaptation (Tauxe, 2002).
3. ***Water availability and quality***: Periods of excessive precipitation and drought can influence both the availability and the microbiological quality of water. New demands on existing water sources could occur if sea levels rise as predicted, adversely impacting water availability (Charron

et al., 2008). An emerging environmental health threat is the decline in global freshwater resources caused mostly by increasing rates of water extraction and contamination. In addition, increased precipitation may support a growth in food supplies which in turn support a greater population of vertebrate reservoirs. Unseasonable heavy rainfalls may cause flooding and decrease vector populations by eliminating larval habitats and creating unsuitable environments for vertebrate reservoirs. Alternatively, flooding may force insect or rodent vectors to seek refuge in houses and increase the likelihood of vector-human contact.

4. ***Zoonotic diseases***: Climate change is an important 'global change' driving the emergence and spread of diseases in livestock and the transfer of pathogens from animals to humans. Climate may have a direct or indirect influence on the susceptibility of animals to disease. For example, exposure to intense cold, droughts, excessive humidity or heat may predispose cattle to complex bacterial syndromes such as mastitis. Because of the sensitivities of vectors to climatic factors, ecological changes such as variations in rainfall and temperature could significantly alter the range, seasonality and incidence of many zoonotic diseases (CDC, 2008). In fact, vector-borne pathogens which respond most rapidly to climatic changes are likely to be rapidly evolving promiscuous agents, transmitted by rapidly reproducing, highly mobile and habitat-generalist vectors (eg: tick borne zoonoses, Rift Valley fever).

5. Vector-borne diseases: By definition, vector-borne diseases (VBDs) possess a vector stage, usually an insect, acarid, mollusc or crustacean that is poikilothermic (cold-blooded) and hence are especially sensitive to changes in climatic variables. Emerging and re-emerging arboviral infections in animals and humans due to alteration in the climate are of greatest concern. In recent years, VBDs have emerged as serious public health problem in countries of the South-East Asia region, including India. Many of these diseases particularly dengue fever and Japanese encephalitis, now occur in epidemic form, almost on an annual basis, causing considerable morbidity and mortality. VBDs are probably the most sensitive to changes in climate parameters. Climate may affect VBDs by affecting the vectors, the disease organisms, the host, transmission pathways, or, more likely, some combination of these. Indeed, biodiversity, which is itself impacted by climate changes, serves important functions in modifying the ecology and epidemiology of vector-borne diseases (Malik et al., 2012).

Climate change can have a range of potential direct and indirect effects on vector biology and on the interactions between vectors and the arthropod-borne disease viruses (arboviruses) (Table-

1). These interactions are highly complex, and the outcomes can be difficult to predict. These interactions are likely to be profoundly influenced by climate change.

Table 1. Effects of climate on vector and disease ecology (Source: Mellor and Leake, 2000; Mellor et al., 2000)

Temperature	• Increased temperature accelerates vector metabolic rate biting rates and feeding frequency leads to enhanced egg production and increased population size • Daily survival rate of vectors decreases as temperature rises an upper limit exists beyond which temperature is detrimental. • Temperature affects geographical distribution of vectors a 1°C rise in temperature is estimated to correspond to 90 km increase in acceptable latitude and 150 m increase in acceptable altitude for a specific vector. • Within vectors, rates of viral infection, virogenesis and transmission are temperature dependent (balanced by shortened individual vector survival at very high temperatures) • Increased environmental temperature converts less – efficient vector species into more important vectors.
Humidity	• High relative humidity favours most metabolic process in vectors; at higher temperature, high humidity prolongs survival, although increased susceptibility to fungal and bacterial pathogens may offset this advantage. • Low humidity decreases daily survival of many arthropod vectors because of dehydration; in some cases also increases blood-feeding rate, an attempt to compensate for high levels of water loss.
Rainfall	• Rainfall limits presence, size and persistence of breeding sites for most blood-feeding insects, including mosquitoes, with aquatic or semi-aquatic larval and pupal stages. • Very heavy or prolonged rain may disrupt vector breeding sites and wash away immature stages or kill them directly.
Wind	• Prevailing winds and wind speed affect passive dispersal levels of vectors some insect vectors disperse for hundreds of kilometres.

Environmental Change	One vector species may be displaced by another; new host populations may be exposed. If a vector is accidentally introduced into an area, a suitable climate enhances chances of establishing breeding populations. Changes to vector range may bring viruses in contact with new potential vector species.

6. Farming and husbandry practices: The impact of and responses to rising temperatures for farming practice are likely to differ across the world. Livestock breeds which are less susceptible to heat may be used, but this change may increase susceptibility to certain pathogens. In some areas, more animals may be moved inside in an attempt to avoid heat exposure and stress, giving increased opportunity for transmission of disease. Changes in animal husbandry practices (e.g. Intermingling or crowding of food animals) in response to natural disaster or climate-induced changes might promote the transmission of pathogens between animals, resulting in greater pathogen load in faeces and increased prevalence of carcass contamination.

7. Food safety issues: Climate change may result in changes in the incidence of food-borne zoonoses and animal pests and possibly in increased use of veterinary drugs (FAO, 2012). New diseases in aquaculture could also easily result in increased chemicals use. Consequently, there may be higher and even unacceptable levels of veterinary drugs in the food chains. Some emerging food borne diseases includes: bacteria- *Vibrio cholera*, *V. parahemolyticum*; enteric viruses- Hepatitis-A, Coxsackie virus; protozoa- *Cryptosporidium, Cyclospora*.

Plausible recommendations and way forward:

Climate change has got profound impact on the animal health and eventually on human health, either directly or indirectly via various ecological processes. Various study models have been carried out simulating the climate change and predict the probable outcome (especially, disease outbreak) although few have controlled successfully for important socioeconomic and environmental influences. The gaps identified in this area would help to come up with some plausible practical recommendations that could be implemented in this arena and would serve as a way forward (FAO, 2012; 2013; 2014). Some of the important recommendations include:

a. **Active global disease surveillance**: Epidemiological surveillance is a critical component of public health and is essential not only for the early identification of emerging diseases and trends but also for resource planning and measuring the impact of control strategies. Presently, the lack of precise knowledge of current disease incidence rates makes it difficult to comment about whether incidence is changing as a result of climatic conditions. As these data are difficult to gather, particularly in remote regions, a centralized computer database should be created to facilitate sharing of these data among researchers.

b. **Interdisciplinary**: Global action involving all sector stakeholders is urgently required to design and implement cost-effective and equitable mitigation strategies, and to set up the necessary supporting policies and institutional frameworks. Recognizing, understanding and preparing for the impact of climate change highlights the need to promote collaborative and interdisciplinary approach of '*One Health*' so as to address the challenges affecting various domains like food safety, infectious diseases given the inter-relationships among environmental impacts, human-animal-plant health impacts and food hygiene. International collaboration amongst researchers as well as interdisciplinary collaboration between specialists such as epidemiologists, climatologists and ecologists has become all the more important, in order to expand the breadth of information. Epidemiological data can be shared with policy-makers to make necessary preventive policies. These inter-relationships are further complicated by the broader public health implications of climate change as well as the food security implications. The best cited instance would be the collaboration between Food and Agriculture Organization of the United Nations (FAO) and the World Organization for Animal Health (OIE) in order to step up their existing collaboration to control animal disease, ensure the safety of food from animal origin and promote safe trade eventually, to strengthen various compartmentalized systems (FAO News, 2014).

c. **Reducing the emission of Green House Gases**: Wider adoption of the existing best practices and technologies in feeding, health and husbandry and manure management – as well as greater use of currently underutilized technologies such as biogas generators and energy-saving devices, could help the global livestock sector cut its outputs of global warming gases as much as 30% by becoming more efficient and reducing energy waste.

d. **Early warning and emergency response systems:** Enhanced early warning systems are essential to reduce the risk of the lives and livelihoods of vulnerable people posed by climate change related natural disasters and emergencies. This requires good collaboration and communication between sectors (e.g. veterinary, food safety and public health) at national and international level. At the same time, emergency preparedness is also essential.

e. **Use of predictive models:** Models can be useful in forecasting likely health outcomes in relation to projected climatic conditions. Predictive modelling is the process by which a model is created or chosen to predict the probability of an outcome. It has potential to predict the probability of global climate change on ecological systems and emerging hazards.

f. **Improvements in public health infrastructure**: Public health training, emergency response, and prevention and control programmes are considered to be the pre-requisites of public health infrastructure. Improved understanding of the adaptive capacity of individuals affected by health outcomes of climate change, as well as the capacity for populations is needed to prepare a response to projected health outcomes of climate change.

In view of above, it becomes quite evident that the policies aiming at formulating the mitigation strategies to minimize the adverse impact of climate change on animal health and productivity must be designed and shared at regional, national as well as international level, since nature has no boundaries. In India, operational integration in policy and programme between various vertical programmes within the health sector as well as with other related sectors such as water, sanitation, and nutrition has also been limited, thereby, resulting in a lack of a holistic approach to health- The 'One Health', which needs to be essentially implemented for the successful and meaningful outcome.

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Chapter 8

Climate smart small ruminant feeding

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Human population is expected to increase from 7.2 to 9.6 billion by 2050 (UN, 2013). This represents a population increase of 33%, but as the global standard of living increases, demand for agricultural products will increase by about 70% in the same period (FAO, 2009). Meanwhile, total global cultivated land area has not changed since 1991 (O'Mara, 2012), reflecting increased productivity and intensification efforts. Global demand for livestock products is expected to double by 2050, mainly due to improvement in the worldwide standard of living. Meanwhile, climate change is a threat to livestock production because of the impact on quality of feed crop and forage, water availability, animal and milk production, livestock diseases, animal reproduction, and biodiversity. (Rojas-Downing et al., 2017)

The livestock sector contributes 14.5% of global GHG emissions (Gerber et al., 2013), and thus may increase land degradation, air and water pollution, and declines in biodiversity. At the same time, climate change will affect livestock production through competition for natural resources, quantity and quality of feeds, livestock diseases, heat stress and biodiversity loss. Therefore, the challenge is to maintain a balance between productivity, household food security, and environmental preservation.

Impact of Livestock on Climate Change

The most important greenhouse gases from animal agriculture are methane and nitrous oxide. Methane, mainly produced by enteric fermentation and manure storage, is a gas which has an effect on global warming 28 times higher than carbon dioxide. Nitrous oxide, arising from manure storage and the use of organic/inorganic fertilizers, is a molecule with a global warming potential 265 times higher than carbon dioxide. The carbon dioxide equivalent is a standard unit used to account for the global warming potential.

In addition to greenhouse gases arising from enteric fermentation and manure storage, feed production together with the related soil carbon dioxide and nitrous oxide emissions is another important hot spot for the livestock sector. Soil carbon dioxide emissions are due to soil carbon dynamics (e.g., decomposing plant residues, mineralization of soil organic matter, land use change, etc.), the manufacturing of synthetic fertilizers and pesticides, and from fossil fuel use in on-farm agricultural operations (Goglio et al., 2018). Nitrous oxide emissions are emitted when organic and inorganic fertilizers are applied to the soil.

Livestock influence climate through land use change, feed production, animal production, manure, and processing and transport. Feed production and manure emit CO_2, nitrous oxide (N_2O), and methane (CH_4), which consequently affects climate change. Animal production increases CH_4 emissions. Processing and transport of animal products and land use change contributes to the increase of CO_2 Emissions. The increasing demand for livestock products has significantly changed the natural landscape. Land degradation is the deterioration of physical, chemical, and biological properties of soil. Land degradation has been recognized as one of the drivers of land conversion from forest to croplands and pastures because producers exhaust their soil resources and thus search for more suitable land (Steinfeld et al., 2006)

The use of manure and synthetic fertilizers for forage and feed crop production, processing of feed, and transport of feed are the most important contributors of GHG emissions related to the livestock sector (IFAD, 2010). These make up 45% of global livestock anthropogenic GHG emissions, consisting primarily as CO_2, N_2O and CH_4 (Gerber et al., 2013). The livestock sector contributes significantly to GHG emissions through the production of nitrogenous fertilizers used to produce crops for animal feed (Steinfeld et al., 2006). Ammonia volatilization loss from synthetic nitrogen fertilizer is an indirect contributor to GHG emissions. Livestock manure releases CH4and N_2O gas. The decomposition of the organic materials found in manure under anaerobic conditions releases methane (EPA, 1999). Liquid manure found in lagoons or holding tanks releases more methane than dry manure (Burke, 2001)

Impact of Climate Change on Livestock

The potential impacts on livestock include changes in production and quality of feed crop and forage, water availability, animal Growth, milk & meat production, diseases occurrence, reproduction and biodiversity. These impacts are primarily due to an increase in temperature and atmospheric carbon dioxide (CO_2) concentration, precipitation variation, and a combination of these factors. Temperature affects most of the critical factors for livestock production, such as water availability, animal production, reproduction and health. Forage quantity and quality are affected by a combination of increases in temperature, CO_2 and precipitation variation. Livestock diseases are mainly affected by an increase in temperature and precipitation variation (Rojas-Downing et al., 2017).

Quality of feed crops and forage may be affected by increased temperatures and dry conditions due to variations in concentrations of water-soluble carbohydrates and nitrogen. An increase of 2^0C will produce negative impacts on pasture and livestock production in arid and semiarid regions. Temperature increases may increase lignin and cell wall components in plants which reduce digestibility and degradation rates, leading to a decrease in nutrient availability for livestock.

Water availability issues due to climate change will influence the livestock sector, which uses water for animal drinking, feed crops, and product processes (Thornton et al., 2009). The livestock sector accounts for about 8% of global human water use and an increase in temperature may increase animal water consumption by a factor of two to three.

Animal health can be affected directly or indirectly by climate change, especially rising temperatures (Nardone et al., 2010). Climate change may induce shifts in disease spreading, outbreaks of severe disease, or even introduce new diseases, which may affect livestock that are not usually exposed to these type of diseases. Global warming and changes in precipitation affect the quantity and spread of vector-borne pests such as flies, ticks, and mosquitoes. In addition, disease transmission between hosts will be more likely to happen in warmer conditions (Thornton et al., 2009). Heat stress due to global warming is likely to severely affect the livestock by decreasing the feed intake and nutrient utilization, decreasing production and reproduction efficiency, degrading the health status and thereby increasing the mortality and overall alterations in the biodiversity of livestock.

Small Ruminant feeding strategies to combat stress due to climate change

While climate change is a global phenomenon, its negative impacts are more severely felt by poor people in developing countries who rely heavily on the natural resource base for their livelihoods. Moreover, rural poor communities rely greatly for their survival on agriculture and livestock that are amongst the most climate-sensitive economic sectors. Among the livestock species, small ruminants are more vulnerable to climate change as they are reared by poor, unprivileged landless/ marginal farmers under extensive system of production. Animals which are more hardy and adapted to harsh climate condition may thrive well while others may either shift to more suitable region or suffer stressful environment. Adverse climate condition is known to influence more severely to non-adapted and high producing sheep and goats (Sahoo et al., 2013)

In view of the climate change, changing land utilization pattern, deforestation, degradation of pastures and rangeland, the gap between availability and requirement of nutrients is increasing.

The small ruminant production system is affected by climate change and at the same time itself contribute to climate change. So for sustainable small ruminant production there is need to adopt strategies to reduce the magnitude of climate change in the long term i.e. mitigation and (ii) to reduce the effect of climate change on livestock i.e. adaptation. However, neither mitigation nor adaptation alone can counter all climate change effects. Thus, it will be necessary to focus on both mitigation, to reduce the level of emission of GHG contributing to global warming, and on adaptation, to support local communities in dealing with the effects (Sahoo et al., 2013).

Feeding strategies for Small Ruminants to combat climatic stress

Small ruminant production within the mixed farming systems is predominantly dependent on available feed and fodders resources including grazing. Feeding and nutrition are the primary constraints for optimum animal production in drylands. During lean/drought periods, shepherds migrate along with their animals in search of fodder. This migration sometimes creates social conflicts with local people for available scarce fodder resources. Further, this could invite new diseases and parasites which pose health problems in small ruminants. Protein is the first limiting nutrient in many grazing forages, particularly in drylands, and protein availability declines in forages as the plant matures towards the end of winter season. When daytime temperatures and humidity are elevated, special precautions must be taken to keep small ruminants comfortable and avoid heat stress. An adequate supply of cool, fresh and clean water is essential to keep the animal's internal temperature within the normal limits and minimize the effect of heat stress. Allow for grazing early in the morning or later in the evening to minimize stress. Monitor mineral feeding closely during periods of high temperatures. Mineral bricks should be made available 24 hours during the summer. Adequate Copper, selenium, zinc, and phosphorus should be supplied through mineral mixture. Maintaining an adequate selenium level ensures the immune system is prepared to fight off respiratory infections. Concentrate mixture (18% DCP and 70% TDN) prepared with locally available feed ingredients should be supplemented @ 1% body weight to all categories of animals. When no green fodder is available, addition of vitamin supplement in concentrate mixture helps in mitigating heat stress. Further, in severe summer or famine conditions, energy intake becomes less compared to expenditure as the animal has to walk more distance in search of grazing resources which are poor in available nutrients. Hence, all the animals should be maintained under intensive system with cut and carry of available fodder. The concept of complete feed using crop residues (60%) and concentrate ingredients should be promoted for efficient utilization of crop residues like redgram stalk, etc.

Further, productivity and profitability from small ruminants can be increased by strengthening feed and fodder base both at village and household level with the following possible fodder production options (Pankaj and Ramana 2013)

Revival of common property resources (CPRs): It is estimated that 60% of the total feed requirements of small ruminants are met by the CPRs. Over grazing in limited CPRs causes impact not only on herbage availability from CPRs but also quality of herbage affecting the productivity of animals adversely; hence there should be some restriction on number and species of animals to be grazed in any CPR as a social regulation. CPRs need to be reseeded with high producing legume and non- legume fodder varieties at every 2-3 years intervals as a community activity. Further, grazing restriction till the fodder grows to a proper stage and rotational grazing as community decision would improve the carrying capacity of CPRs.

Intensive rainfed fodder production systems: Growing of two or more annual fodder crops as sole crops in mixed strands of legume (Stylo or cowpea or hedge Lucerne, etc) and cereal fodder crops like sorghum, ragi in rainy season followed by berseem or Lucerne etc., in rabi season in order to increase nutritious forage production round the year.

Short duration fodder production from tank beds: Due to silt deposition, tank beds are highly fertile and retain adequate moisture in the soil profile for cultivation of short season fodder crops like sorghum and maize during winter and or summer.

Integrated fodder production systems: Fodder crops like Stylo hamata and Cenchrus ciliaris can be sown in the inter spaces between the tree rows in orchards or plantations as hortipastoral and silvopastoral systems for fodder production.

Fodder production systems through alley cropping: Alley cropping is a system in which food/fodder crops are grown in alleys formed by hedgerows of trees or shrubs (Leucaena leucocephala, Gliricidia, Calliandra, Sesbania etc.). The essential feature of the system is that hedgerows are cut back at planting and kept pruned during cropping to prevent shading and to reduce competition with food crops. The main objective of alley cropping is to get green and palatable fodder from hedgerows in the dry season and produce reasonable quantum of grain and stover in the alleys during the rainy/cropping season. This calls for cutting back (lopping) of hedge rows during the dry season. A welcome feature of alley cropping is its ability to produce green fodder even in years of severe drought.

Perennial non-conventional fodder production systems: Perennial deep rooted top feed fodder trees and bushes and modified plants of cactus are highly drought tolerant and produce top fodder should be planted in CPRs and farm bunds. Sowing of inter spaces of tree rows with drought tolerant grasses further enhance forage production from waste lands.

Fodder production systems in homesteads: Azolla, a blue green algae which has more than 25 % CP and a doubling time of 5-7 days can be grown in pits at backyards depending on the number of animals owned by the farmer. It is more nutritious and can be fed to small ruminants after mixing with concentrate mixture.

Hydroponic Fodder Production Systems: By this method, fodder can be produced in large quantities within 8 days from seed to grass for all livestock. These include barley, oats, lucerne and rye grass. Growing grass fodder systems hydroponically is now becoming popular in drought prone areas. Hydroponic fodder production however requires large investment in the form of a commercial greenhouse, continuous supply of water and power.

Intensive irrigated fodder production systems: High yielding perennial (hybrid Napier varieties like CO-3, CO-4, APBN-1 etc.,) and multicut fodders varieties (MP Chari, SSG etc.) could be choice of fodder crops under this system as it efficiently utilizes limited land resources and other agricultural inputs for getting maximum forage per unit area. It can be done where ever water is available and transported to deficit areas and fed to small ruminants.

Year-round forage production systems: Cultivation of a combination of suitable perennial and annual forages for year round nutritious fodder supply using limited water resources. It consists of growing annual leguminous fodders like cowpea or horse gram, etc. inter-planted with perennial fodders like Co-3, CO-4, APBN-1 varieties of hybrid Napier in kharif and intercropping of the grasses with berseem, Lucerne, etc. during rabi season.

Usage of unconventional resources: The available agro industrial by products from agriculture and industries which are suitable for feeding to animals like palm press fibre, fruit pulp waste, vegetable waste, brewers' grain waste and all the cakes after expelling oil etc., and thorn-less cactus should be used as feed to meet the nutritional requirements of animals.

Fodder conservation: Excess fodder produced during rainy season can be conserved in the form of silage or hay and it can be fed to animals during lean season to meet the requirements. Silage being a semi fermented feed, is easily digestible and produces relatively lesser quantities of GHGs in the rumen due to faster rate of passage in GI tract.

Feed processing: When forages are chopped or ground into smaller particles, the surface area increases leading to increase in efficiency of digestion, faster rate passage and there by decreases the GHG emissions.

Intensive sheep production with Total Mixed Rations (TMRs):

In the recent times due to increasing demand for quality mutton, many enthusiastic farmers and entrepreneurs are showing interest in taking up sheep rearing on a large scale in commercial lines. But, unorganized nature of sheep rearing and marketing in addition to the shrinking grazing lands and hardships associated with traditional systems of rearing are averting them from venturing into this sector. Alternative systems of rearing wherein one can have complete control over the production system can encourage people to undertake sheep rearing in a professional and commercial manner. Rearing sheep with complete feeds which is also called as Total Mixed Ration (TMR) is an alternative way for large scale commercial production suitable for farmers who can invest substantial amount of money for commercial sheep rearing on large numbers.

Total Mixed Ration (TMR) or complete feed comprises of roughage and concentrate ingredients grinded and mixed in definite predefined proportions to meet the maintenance and growth requirements of lambs. The roughage component here may comprise of cheaply available crop residues and agro-industrial by-products like maize straw, ground nut straw, maize cobs etc. Depending on the palatability, nutrient content and anti-nutritional factors present in them, certain limitations are specified for the level of inclusion of these residues in the complete feeds. The remaining portion of complete feed comprises of concentrate ingredients like grains, millets, oil seed cakes, brans, molasses, mineral mixture, salt, vitamins etc., as per the formulation. The overall level of inclusion of each ingredient in the complete feed depends on the level of nutrients required in the final complete feed. Depending on the availability of different crop residues and agro industrial by- products in different localities, the composition can be changed accordingly with the advice of the animal nutritionist.

The large scale field studies with TMR conducted by ICAR- NRC on Meat by establishing rural feed processing units in the rural areas have shown promising results for large scale adoption of this technology. This technology can be utilized for large scale commercial small ruminant production by effective utilization of locally available crop residues as feed resources.

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Chapter 9

Climate smart meat production: Cultured meat

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1. Introduction

Demand for food, especially animal protein is rapidly raising across the world due to ever growing population, raising standard of living and urbanization. Meat and meat products play important role in meeting the animal protein requirement. According to Department of Animal Husbandry, Dairying & Fisheries (DAHD&F) data, poultry is the highest consumed meat in India with total contribution of 50.06% to the total meat production (2018-19). It is followed by buffalo (19.05 %), goat (13.53 %), sheep (8.36 %), pig (4.98 %) and cattle (4.02 %). Fiala (2008) has suggested that if meat consumption patterns continue along the same path, then the consumption rates will be 72% higher than 2000 levels in the year 2030. Demand for meat is growing in rapidly developing countries, particularly India, China and Brazil (Cheminitz and Becheva, 2014; OECD, 2011) Reports indicate that livestock farming takes up to 30% of earth's land surface, of that, 70% of arable land is consumed in livestock farming (Edwards, 2017).The livestock sector was observed as a significant contributor to anthropogenic source of atmospheric pollutant, as it releases gases such as, ammonia, nitrous oxide, methane and carbon dioxide (Gold, 2004). Among these gases nitrous oxide, methane and carbon dioxide contribute to global warming (Lesschen et al, 2011). There also arise the risk of animal-borne diseases such as bovine spongiform encephalopathy, Swine and avian influenza (Vleeschauwer et al, 2009). To meet the demand for meat and meat products of growing Indian population, there is a need to develop innovative and sustainable approaches. Cultured meat fits these requirements.

2. Cultured meat

Cultured meat is the meat produced by growing muscle cells in a media rather than rearing the animals and slaughtering them. In other words, it is the meat grown outside the animal. Muscle stem cells extracted from the tissue of animals is used as starting material for producing the cultured meat. Ideally, cultured meat must have same sensory and nutritional profile similar to that of conventionally produced meat to gain the consumer acceptance. Basic steps in cultured meat production involve: (a) extraction of the required stem cells from the animal tissue; (b) differentiation and multiplication of the cells in the media on the scaffold to get the proper texture and shape; (c) separation of the cultured muscle cell culture from the media and processing to get the required product. To get the complete product, co-culturing of myoblasts, fibroblasts, adipoblasts etc is required to be standardized prior to upscaling. Cell-based meat production will require up to three principal material inputs: the original cell line, the cell culture medium, and scaffold. A cell line must be both stable and immortalized: it must behave consistently and predictably, while also maintaining the capacity to divide, through many generations. The starter cells are added to a bioreactor along with cell culture media, which supplies nutrients to the cells to enable them to multiply and create the biomass that will eventually be consumed after processing using nonmeat ingredients. Scaffolds provide a support structure for the cells in order to help create a desirable meat-like texture.

Cultured meat could reduce water use, land use, greenhouse gas emission, and eutrophication potential, when compared to traditional livestock meat production. Tuomisto et al. (2011) compared cultured meat to conventionally produced beef, sheep, pork and poultry, where they found that approximately 78-96% less greenhouse gas emission, 99% less land use, 82-96% less water use, and 7-45% less energy use, could occur depending upon the type of meat product. While lot of research work is being done globally in this sector, cultured meat research is in nascent stage in India. However, many private firms are looking to invest in this area.

3. Basic steps involved in production of cultured meat

The cultured meat production involves the isolation of the cells from the biopsy, culturing of the cells in suitable medium, differentiation of the cells on scaffolds and finally the scale up of the process in the bioreactors.

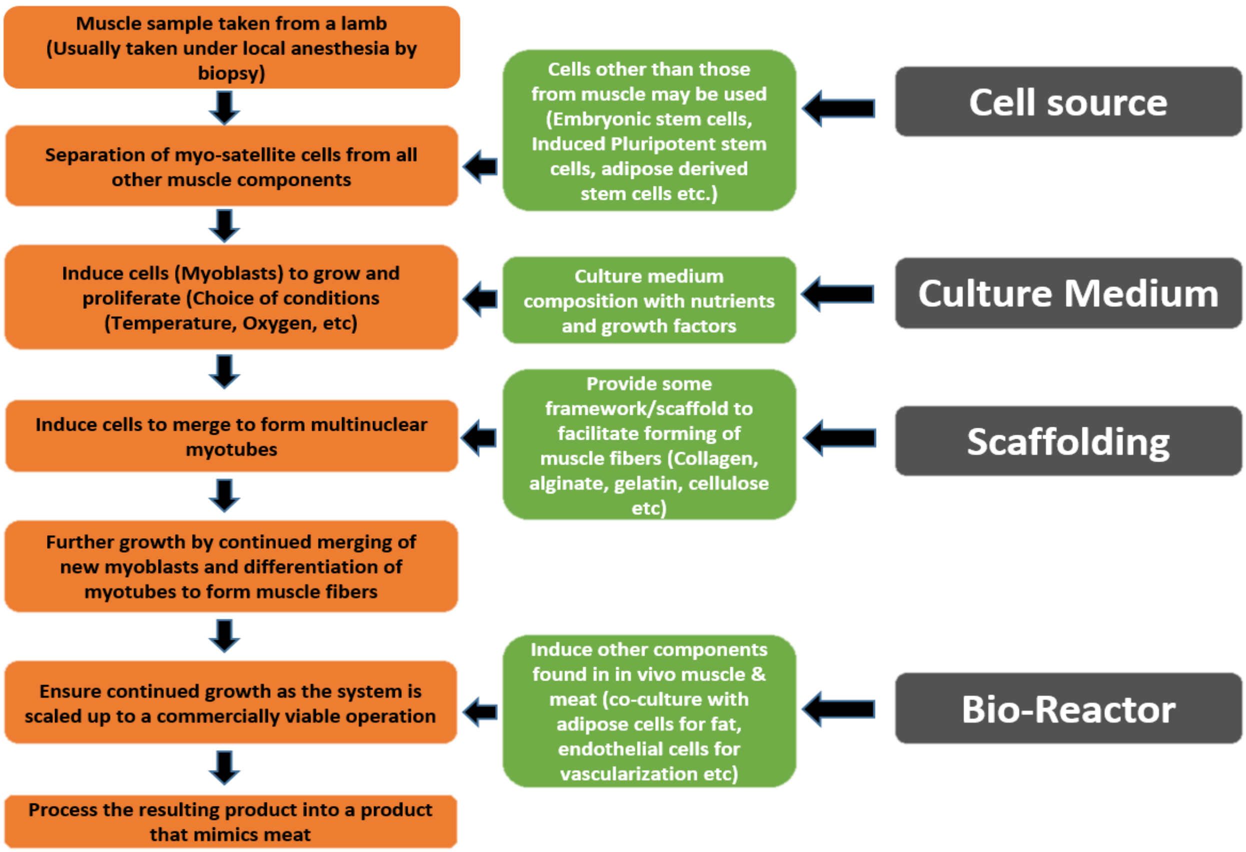

Fig 1: Flow diagram showing some of the steps involved in the production of cultured meat

Brief technical details related to cultured meat production are given below.

Cells for the cultured meat: The ideal cells for cultured meat mustbe able to divide infinitely, differentiate into muscle cells, able to grow on scaffolds for 3D culture and conditioned to get mature and form muscle fibers. Different types of cells having the potential to divide multiple times are: induced pluripotent stem cells (Vogel and Holden,2008), embryonic stem cells (Pandurangan et al., 2015), adult stem cells (Roobrouck et al., 2008) and muscle satellite stem cells (Asakura et al., 2001). The native muscle tissue will contain fat cells, vascular tissue and nervous tissue. We can co-culture the muscle cells with the above mentioned cells to provide the natural feel to the final product.

Culture Medium: The ideal culture medium must support the muscle cells proliferation and differentiation. Commonly used cell culture medium for muscle cells contains basal media along with fetal bovine/calf serum or horse serum. The different basal media include DMEM, Hams F12 etc. The problem with serum is that it is costly, animal dependent and may be presence of endotoxins. Further, cultured meat with animal derived serum may not find much acceptance among the consumers. Hence, research to identify serum free media is being undertaken.Some of the commercially available serum free media to support growth of muscle cells include L15, Ultroser G and AIM-V (Fujitha et al., 2010). Mushroom extract, Cyanobacteria and different combinations of growth factors like basic fibroblast growth factor (bFGF), vitreonectin, glial cell derived neurotrophic factor (GDNF), brain cell derived neurotrophic factor (BDNF), cardiotrophin 1(CT1), neurotrophin3 and 4(NT 3&4)are used to compensate usage of serum in muscle cell culture (Das et al.,2009).Different factors which helps in the differentiation into myotubes and myofibers includes mechanical, electromagnetic, gravitational and fluid flow methods (Kosnik et al.,2003; De Deyne.,2000), horse serum (2% to 10%), biochemically by inducing/stopping signaling pathways like TGFß1,Pax7, Notch and Wnt and repetitive contraction and relaxation can enhance the length of skeletal muscle by at least 10% (Powell et al, 2002).

Scaffolds: The ideal scaffold should possess the qualities of biocompatibility, easily separable or edible, possess mechanical strengths to withhold muscle contraction and relaxations, maximize the media diffusion and suitable for bioreactor culture. The literature available reports that the muscle cells were cultured on different scaffolds includes chitosan (mushroom), alginate (sea weed), gelatine (salmon), fibrin hydrogel, cellulose, silicone with wavy micro patterned surface and collagen in different forms like beads, spheres, meshwork (Edelman et al, 2005). Recently, there are reports on using decellularized iceberg lettuce, spinach plant leafs apple hypanthium and leek as scaffold for muscle cell culture (Modulevsky et al.,2014). The major challenge with scaffolds is the removal of the scaffolds system after the culture. Generally, the cells are detached from the scaffold using mechanical or enzymatic methods which destructs the extra cellular matrix and damage the cells also. There are reports on thermoresponsive coating which by cooling change from hydrophobic to hydrophilic and releases the intact cell sheets of cultured cells and extracellular matrix (Da Silva et al., 2007). The degradation/digestion of the attachment protein laminin also helps in the removal of cells as a confluent sheet from a non-adhesive micro patterned surface (Lam et al., 2009).

Up scaling of the cell culture using Bioreactors: Bioreactors are required for the large scale production of the cultured meat. The ideal bioreactor should support the cells with the scaffold and maintain all the parameters like mass transfer, oxygen level, shear stress and flow of the medium at optimum level to produce high output. There are different bioreactors with specific functions. The different bioreactors studied for cultured meat are rotating wall vessel bioreactors, direct perfusion bioreactors and micro carrier based bioreactors.In direct perfusion reactorsthe scaffolds with porosity will be used and media will flow through the scaffold and gas exchange will happen in an external fluid loop (Carrier et al, 2002). Direct perfusion bioreactors support scaffold based culture with high mass transfer and significant shear stress. Rotating wall vessel bioreactors maintain *invivo* conditions by adjusting rotating speed which in turn balances the centrifugal force, drag force and gravitational force and finally allows the 3D culture to be submerged in the medium (Vander Weele and Tramper, 2014). These bioreactors provide high mass transfer with less shear stress. In some cases they have tried to co-culture myoblasts, embryonic fibroblasts and endothelial cells to get the cultured meat. In some cases to mimic in vivo conditions myoblasts are cultured with fat cells. .

Micro carrier based reactors: Micro carriers are used to support the cells in 3D environment. There are two types of micro carrier based reactors: (a) suspension of the micro carriers and (b) packed bed rector. In packed bed reactors the medium can be oxygenated before entering into the reactor and the flow of the medium also continuous but the available literature restricting its use up to 30lit. Micro carriers in suspension help cells to grow on them.The seeding densities of the cells have different effects on the characteristics of the cells in this type of rectors. The problem with micro carriers based bioreactors are formation of aggregates and shear stress due to agitation (Mortiz et al., 2015).

4. International status

After Dr. Post has produced the first cultured meat burger successfully in 2013, a variety of startups and organizations committed to developing or advancing cultured meat have been founded. The first International Conference on Cultured Meat was hosted by Maastricht University in 2015. As the field has grown, nonprofit organizations such as New Harvest (Albrecht, 2018) and The Good Food Institute have begun hosting annual conferences to convene industry leaders, scientists, investors, and potential collaborators from parallel industries. As of 2019, over two dozen startups working on cultured meat have been founded.

Memphis Meats, a Silicon Valley startup founded by a cardiologist, launched a video in February 2016 showcasing its cultured beef meatball (Bunge, 2016), and later in March 2017, it showcased chicken tenders and duck a l'orange, the first cultured poultry-based foods shown to the public (Bunge, 2017). An Israeli company, SuperMeat, ran a viral crowd funding campaign in 2016 for its work on cultured chicken (Chang, 2016). Finless Foods, a San Francisco-based company aimed at cultured fish, was founded in June 2016. In March 2017 it commenced laboratory operations and progressed quickly. Director Mike Selden said in July 2017 to expect bringing cultured fish products on the market within two years (by the end of 2019). (Jon Card, 2017)

In March 2018, JUST, Inc. (in 2011 founded as Hampton Creek in San Francisco) claimed to be able to present a consumer product from cultured meat by the end of 2018. According to CEO Josh Tetrick the technology is already there, and now it is merely a matter of applying it. JUST has about 130 employees and a research department of 55 scientists, where lab meat from poultry, pork and beef is being developed. They would have already solved the problem of feeding the stem cells with only plant resources. JUST receives sponsoring from Chinese billionaire Li Ka-shing, Yahoo! co-founder Jerry Yang and according to Tetrick also from Heineken International amongst others. (Mac van Dinther, 2018)

The Dutch startup Meatable, consisting of Krijn de Nood, Daan Luining, Ruud Out, Roger Pederson, Mark Kotter and Gordana Apic among others, reported in September 2018 it had succeeded in growing meat using pluripotent stem cells from animals' umbilical cords. Although such cells are reportedly difficult to work with, Meatable claimed to be able to direct them to behave using their proprietary technique in order to become muscle cells or fat cells as needed. The major advantage is that this technique bypasses fetal bovine serum, meaning that no animal has to be killed in order to produce meat (Erin Brodwin, 2018). That month, it was estimated there were about 30 cultured meat startups across the world. A Dutch House of Representatives Commission meeting discussed the importance and necessity of governmental support for researching, developing and introducing cultured meat in society, speaking to representatives of three universities, three startups and four civil interest groups on 26 September 2018 (Arnews, 2018).

In August 2019, five startups announced the formation of the Alliance for Meat, Poultry & Seafood Innovation (AMPS Innovation), a coalition seeking to work with government regulators to create a pathway to market for cultured meat and seafood (Evich, 2019). The founding members include JUST, Inc., Memphis Meats, Finless Foods, BlueNalu, and Fork & Goode (Purdy, 2019). In 2019, the Foieture project was launched in Belgium with the goal of developing cultured foie gras (the name is a portmanteau of 'foie' and 'future') by a consortium of 3 companies (cultured-meat startup Peace of Meat, small meat-seasoning company Solina, and small pâté-producing company Nauta) and 3 non-profit institutes (university KU Leuven, food industry innovation centre Flanders Food, and Bio Base Europe Pilot Plant). With the others' assistance, Peace of Meat stated in December 2019 it seeks to complete its proof of concept in 2020, to produce its first prototype in 2022, and to enter the market in 2023. That month, the Foieture project received a research grant of almost 3.6 million euros from the Innovation and Enterprise Agency of the Flemish Government (Dieter, 2020). In May 2020, Peace of Meat's Austrian-born cofounder and scientific researcher Eva Sommer stated that the startup was then able to produce 20 grams of cultured fat at a cost of about 300 euros (€15,000/kg); the goal was to reduce the price to 6 euros per kilogram by 2030. Piece of Meat would soon build two laboratories in the Port of Antwerp (Yves, 2020).

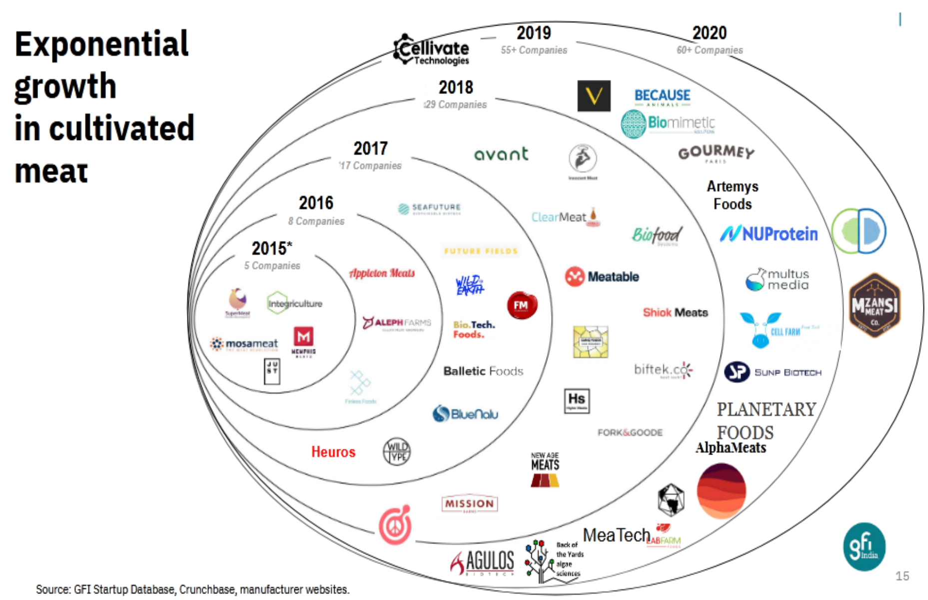

Fig. 2: Pictorial depiction of exponential growth in cultured meat startups in the world

5. Indian status

India meat consumption is increasing day by day about 300 crores chickens and 8 crores goats are slaughtered each year in India although there is a thought that it is an all vegetarian country. Over 70% of India is non-vegetarian (TIFAC, 2018). The first research project in the area of cultured meat is being carried out by Centre for Cellular and Molecular Biology, Hyderabad in collaboration with ICAR – National Research Centre on Meat, Hyderabad. Recently there is a news article regarding lab grown chicken meat from Dr. Biman Mandal, IIT-Guwahati, where they claimed that they produced the lab grown chicken meat which is going to be patented. In India ahimsa food is the first company to enter into "Mock meat" production. At IIT Delhi recently to discuss various aspects of cellular agriculture TIFAC event (2018) was organized on the next food revolution which brought scientists, businessman, policymakers, politicians and religious leaders on a common platform.

6. Conclusion and future prospective

Cultured meat can contribute significantly to meeting the animal protein requirements of the ever growing population. The concept holds potential to help in combating the negative effect on the environment caused by livestock and meat production. However, safety aspects of the product need to be ensured by putting proper checks at various levels from production to consumption. While countries like Singapore, USA, Israel and Netherlands are working aggressively to produce cultured meat at commercial level, in India we are still in nascent stage. India must put full effort to undertake research and produce cultured meat at commercial level as it holds potential to create business opportunities, create employment, earn foreign exchange by exports apart from promising to produce the meat with least impact on the environment.

7. References: Can be taken from the author by putting mail request

Chapter 10

Climate-smart innovations for livestock products processing

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Introduction

The Green House Gas (GHG) emissions in livestock product processing can be reduced substantially through the changes in product processing, more efficient energy use, and waste management. Reducing post-harvest food losses reduces emissions per unit of food consumed. The emission intensities (i.e., emissions per unit of product) vary from commodity to commodity. They are highest for beef (almost 300 kg CO2-eq per kilogram of protein produced), followed by meat and milk from small ruminants (165 and 112kg CO2-eq.kg, respectively). Cow milk, chicken products, and pork have lower global average emission intensities (below 100 CO2-eq/kg protein). Results show that products from ruminants, especially meat, contribute more to GHG emissions per kg of protein than monogastric livestock. Beef and meat from buffaloes are the livestock products with the highest CO2 emissions (295 and 404 per kilogram of protein, respectively), followed by meat from small ruminants (201/kg of protein). Chicken eggs contribute the least GHG emissions (31/kg of protein).

There are striking differences in global emission intensities among commodities. For example, on a worldwide scale, the emission intensity of meat and milk, measured by output weight, corresponds on average to 46.2 kg CO2 eqv. per kg of carcass weight (CW), 6.1 kg CO2 eqv./kg CW and 5.4 kg CO2 eqv./kg CW for beef, pork, and chicken meat, respectively, and 2.8 kg CO2 eqv./kg of milk (FAO, 2013a, and b). There is significant variability in emissions across the different regions. The emissions from Europe and North America range between 1.6 and 1.9 kg CO2 eqv. per kg fat and protein corrected milk (FPCM) at the farm gate. The highest emissions are estimated for sub-Saharan Africa, with an average of 9.0 kg CO2 eqv./kg FPCM at the farm gate. GHG emissions for Latin America and the Caribbean, Near East and North Africa, and South Asia, range between 3 and 5 kg CO2 eqv./kg FPCM at the farm gate. The global average is estimated at 2.8 kg CO2 eqv. (FAO, 2013a).

The global dairy sector also found GHG emissions to be inversely related to productivity. At very low levels of milk production (200 kg per cow per year), emissions were found to be 12 kg CO2 eqv./kg FPCM compared to 1.1 kg CO2 eqv./kg FPCM for high production levels (about 8 000 kg of milk). This reflects the strong relationship between livestock intensification and GHG emissions globally (Gerber et al., 2011). India is a significantly high source of greenhouse gas emissions compared to many other regions in the world. India alone accounts for about 6.5 percent of the world's total greenhouse gas emissions. According to the World Resources Institute, India's total emissions in 2014 from all GHGs amounted to approximately 3,200 MTCO eq out of the world's 48,892 MTCO eq. Out of India's 2014 average greenhouse gas emissions of 3,200 MTCO eq, 626.86 MTCO eq is attributed to agriculture. (WRI, 2020).

Climate smart technologies for processing livestock products

1. Process management

1.1. Energy efficiency

Expanding the livestock product value chains' development will lead to an increase in energy demand; for example, as more products are processed, mechanization increases, and transport requirements grow. The amount of energy used in processed products is particularly concerning. The efficient use of energy, including renewable energy, is a vital climate-smart livestock products strategy to minimize fossil fuels. The increasing energy efficiency and conservation can be achieved by using machinery and equipment with higher energy efficiency on the processing plant and elsewhere in the livestock value chain. The energy-efficient equipment uses less energy per unit of product.

Strategies for energy efficiency

- Using natural ventilation in processing plants instead of cooling systems with high energy consumption
- Efficient systems for cooling milk at dairy farms
- Efficient methods for heating water
- Replacing incandescent lighting with high-efficiency lights like LED
- Efficient livestock watering systems
- Efficient equipment for manufacturing
- Reduction of transport along the value chain, e.g., sourcing supplies locally

1.3. Machinery

Case study: Solar milk cooling, Tunisia

An innovative technology to cool milk on the farm is entirely based on renewable energy. The system is composed of conventional 40 liter milk cans with an ice compartment and removable insulation. The ice is produced by a solar-powered freezer that can harness solar radiation with an adaptive control unit. The system comprises photovoltaic panels, small batteries, an adaptive control unit, a charge controller, and a commercially available direct current refrigerator with an integrated fan and 25 two-liter plastic cans for the ice blocks. The system can cool down 30 liters of milk by using ice as a cooling medium. The introduction of the solar milk cooling system has shown significant results in improving milk quality during transport and overnight storage.

Adoption of renewable energy (Biodigester and solar power)

The biodigester helps control waste run-off from product processing and generates methane gas for cooking fuel and lighting. The solar electricity system is used to pump water from a rainwater collection tank to the processing plant and provide solar power for machinery operation and lighting of the premises.

2. Alternative processing methods

The FAO estimates that CO_2 emissions from animal processing total several tens of millions of tonnes per year. The processing and international transport: 0.03 gigatonnes CO_2 eqv. (less than 0.1 percent of the sector’s emissions). The processed animal products typically come from intensive systems, although energy costs vary widely depending on the product. The processing meat from sheep, according to one study, is very energy costly, with 10.4 megajoules (MJ) used per kg of carcass compared to the energy required for processing beef, which uses 4.37 MJ per kg. The processing eggs, too, are energy-intensive, with more than 6 MJ used per dozen eggs.

Strategies for climate-smart processing methods

- Strengthen processing facilities to be able to withstand the potential impacts of climate change (e.g., extreme weather events, biological contaminants)
- Reduce energy use (e.g., invest in upgraded energy-efficient processing; use renewable energy sources, where possible).

- Use steam as an alternative to water for processing products
- Effective temperature control in the processing of products

3. Diversification of products

The alternative proteins that can act as substitutes for traditional animal-based food attract considerable financial investment, research attention, and consumer interest as a pathway to meeting the nutritional needs and food demands. The latest innovations in product technology with climate change relevance include cultured meat and meat analogues/plant-based meat/protein.

4. Integrated product development

The strategies for the integrated product development for mitigating global warming are as follows.

- The efficient use of plant sources in livestock products for improving quality, shelf-life and functionality.
- The production raw materials and processing of products in the same location for energy efficiency and minimizing GHG emissions.
- Improving the productivity of the livestock products with efficient machinery and automated processing system.
- Encouraging the concept of land-plant-animal-product integration for efficient production and productivity

5. By-product utilization and waste management

The losses and waste also mean that the GHG emitted during their production has served no useful purpose. The energy embedded in global annual food losses is thought to be around 38 percent of the whole food chain's total final energy (FAO, 2016). The use of other natural resources like water will also be reduced substantially when the amount of waste is reduced. The utilization of wastes from product processing either as a rendered meal or treated effluent improves barren soils and sustained vegetable production. The availability of manure for compost contributed to decreased dependence on chemical fertilizers, a reduction in greenhouse gas emissions, and increased soil fertility to facilitate the production of higher quality produce.

Strategies for reduction of losses and waste

- Ensuring proper sanitation at all stages of the value chain
- Appropriate processing, labeling, and packaging, distribution, transport, and storage of livestock products to extend shelf life
- Recycling of waste, e.g., using rendered by-products as animal feed/fertilizer
- Increased integration in the circular bioeconomy:
  - ✓ The annual feed intake of livestock is about 6 billion tonnes of dry matter, or 20 percent of biomass's global human harvest.
  - ✓ Crop residues and agro-industrial by-products such as bran, molasses, or oilseed cakes represent nearly 30 percent of the total livestock feed intake.
- Ensure efficient manure management:
  - ✓ Manure is linked to both CH_4 and N_2O emissions.
  - ✓ 2.2 gigatonnes CO_2 eqv. (31 percent of the sector's emissions), mainly through manure storage, application, and deposition (CH_4, N_2O, NH_3).
- Active and intelligent packaging for reducing food losses
- IoT sensors and networks, robotics, mobile computing

6. Water management

Deutsch et al. (2010) estimated that the livestock sector uses an equivalent of 11 900 km^3 of freshwater annually, which is approximately 10 percent of the annual global water flows (calculated at 111,000 km^3). Many of the impacts of climate change are resulting from the effects of limited water availability. The reduced rainfall, increased rainfall variability, increased evaporation rates, and extreme weather events will affect product production and potable water shortages, which will affect the livestock product value chains in general. Simultaneously, increased temperatures will lead to an overall increase in water requirements, degradation of water quality, and increasing competition over water resources.

Strategies for climate smart efficient water management

- Efficient water harvesting techniques in the processing plant
- Weather forecasting
- Production of minimum water usage livestock products
- Reduction of water wastage or recycling wastewater
- Increased water storage

- Efficient and low-energy irrigation methods for the green cover
- Investing for water-smart investments
- Development of policy and regulations related to efficient water use

7. Marketing and distribution

The strategies for mitigating climate change due to the marketing and distribution of livestock products include the following measures.

- Invest in packaging that maintains quality and safety under climate risks, such as extreme heat.
- Climate-proof market facilities
- Improve coordination within the value chain to increase efficiency in transportation and distribution to reduce post-harvest losses.
- Encourage retail outlets to take measures to minimize refrigerant leakage and reduce energy use.
- Transparency from farm to fork through blockchain
    - ✓ Food Blockchain will leverage a series of interconnected sensors to introduce comprehensive food quality assurance without humans' intervention.

8. Capacity development

The capacity building of trained human resource is essential to mitigate the impact of GHG emissions released from the processing of livestock products

Conclusion

The adoption of energy-efficient processing innovations will reduce the vulnerability of livestock product processing to climate change. Information and Communication Technology (ICT) should be used to improve access to information and prevailing gaps in knowledge about livestock products' climate-smart processing. Climate-smart livestock product processing should be brought into the mainstream of curricula at institutions of higher learning. Institutional and financial support is imperative to enable smallholder farmers to shift to climate-smart processing of livestock products.

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Chapter 11

Carbon foot print and global warming due to livestock production: myths and facts

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Introduction

The scientific evidence of anthropogenic interference with the climate system through GHG emissions has led to worldwide research on assessing impacts that could result from potential climate change associated with GHG accumulation. As ecosystems are sensitive to climatic changes, it is necessary to examine likely impacts of climate change on various sectors /aspects within ecosystems providing comprehensive understanding of these effects of climate change. While carbon dioxide receives the most attention as a factor relative to global warming, there are other gases to be considered, including methane (CH_4), nitrous oxide (N2O) and chlorofluorocarbons (CFCs). CH_4 has a global-warming potential 25 times more potent than carbon dioxide, making CH_4 one of the most important greenhouse gases because of its stronger molar absorption coefficient for infrared radiation and its longer residence time in the atmosphere. The rising concentrations of CH_4 are correlated with increasing populations and currently about 70% of CH_4 production arises from anthropogenic sources, while the remainder is from natural sources.

The global release of CH_4 from agricultural sources accounts for two-thirds of the anthropogenic CH_4 sources. These sources include rice growing, fermentation of feed by ruminants (enteric CH_4), biomass burning, and animal wastes. CH_4 is a potent greenhouse gas and its release into the atmosphere is directly linked with animal agriculture, particularly ruminant production. In fact livestock are produced throughout the world, and are an important agricultural product in virtually every country. Globally, ruminant livestock are responsible for about 85 Tg of the 550 Tg CH_4 released annually. Ruminant animals, particularly cattle, buffalo, sheep, goat and camels produce significant amounts of CH_4 under the anaerobic conditions present as part of their normal digestive processes. This microbial fermentation process, referred to as 'enteric fermentation', produces CH_4 as a byproduct which is released mainly through eructation and normal respiration, and small quantities as flatus.

As animal production systems are vulnerable to climate change and are large contributors to potential global warming through CH_4, it is very vital to understand in detail enteric CH_4 emission in different livestock species. Before targeting the reduction strategies for enteric CH_4 emission, it is very important to know the mechanisms of enteric CH_4 emission in livestock, the factors influencing such emission and prediction models and estimation methodology for quantification of enteric CH_4 emission. The thorough understanding of these will in turn pave way for formulation of effective mitigation strategies for minimizing enteric CH_4 emission in livestock.

Global Warming- A reality

Global warming refers to the increased temperature of Earth's surface, including land, water and near-surface air. Global warming is caused by excessive quantities of greenhouse gases emitted into Earth's near-surface atmosphere. Greenhouse gases are both man-made and occur naturally, and include a number of gases, including: carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and water vapour. Optimal amounts of naturally occurring greenhouse gases, especially water vapour, are necessary to maintain the Earth's temperature at inhabitable levels. Without greenhouse gases, Earth's temperature would be too cold for human and most other life. However, excessive greenhouse gases cause Earth's temperature to warm considerably which cause major and occasionally catastrophic, changes to weather and wind patterns, and the severity and frequency of various types of storms. Man-made greenhouse gases have increased greatly in the last 50 years. Among the largest sources of man-made gases are fossil-fuel burning vehicles, worldwide deforestation, and sources of methane such as sandfills, septic systems, livestock, and fertilizers.

Earth has warmed significantly since the mid-20th century due to an increase in greenhouse gases that trap heat on Earth. Physical evidence of global warming is widespread and startlingly significant. Average (Earth) temperatures have climbed 1.4 degrees Fahrenheit (0.8 degree Celsius) around the world since 1880, much of this in recent decades, according to NASA's Goddard Institute for Space Studies. The rate of warming is increasing. The 20th century's last two decades were the hottest in 400 years and possibly the warmest for several millennia, according to a number of climate studies. And the United Nations' Intergovernmental Panel on Climate Change (IPCC) reports that 11 of the past 12 years are among the dozen warmest since 1850. Arctic ice is rapidly disappearing, and the region may have its first completely ice-free summer by 2040 or earlier. Polar bears and indigenous cultures are already suffering from the sea-ice loss. Glaciers and mountain snows are rapidly melting—for example, Montana's Glacier National Park now has only 27 glaciers, versus 150 in 1910. An upsurge in the amount of extreme weather events, such as wildfires, heat waves, and strong tropical storms, is also attributed in part to climate change by some experts.

Carbon footprint of different livestock products

On an annual basis, the food production chain produces 13.7 billion metric tons of carbon dioxide equivalents (CO2 eq.) (Poore and Nemecek, 2018). Among the food supply chain, meat and dairy industry generates a considerable amount of GHG emissions. Livestock alone symbolizes at least 14% of the overall total global emissions (Springmann et al., 2016). Over half of the emissions from food systems from livestock are because production steps are carbon intensive. For example, to produce beef, all that happens at the farm level (methane emissions from cows, farm machinery), land use change, and growing feed crops (Poore and Nemecek, 2018). Transportation, processing, and packaging fill out the leftover categories.

In a latest research done by Marbach and Gaillac, (2021) they analysed the carbon footprint of meat and dairy products based on protein content, carbon footprint, and carbon footprint per g of protein. And they noticed that protein content range of unprocessed meat including beef, lamb/mutton, pork, veal, and chicken is around 20g/100g (edible) and other dairy products including milk and cheese is 3g/100g (edible) and 36g/100g (edible) respectively. Based upon the carbon footprint it is found that meat from beef, lamb/mutton, and veal, ranging in average from 2−8kgCO_2 eq./100 g(edible). As well as other dairy products such as milk and yogurt, with about 100 − 300gCO_2 eq./100 g(edible) and cheese 5.8kgCO_2eq./100g (edible). Hence, carbon footprint per g of protein calculated by dividing carbon footprint (per g of edible weight) from protein content (per g of edible weight) and found that meat from beef and lamb/mutton ranges from 190-220gCO_2eq./g protein and from pork and chicken 40 and 30gCO_2eq./g protein respectively. From other dairy products like milk, cheese, and yogurt show 60,50, and 25gCO_2eq./g protein respectively. Therefore, ruminant meat and dairy have a high carbon footprint per g of protein, and at the same time other meats (such as pig and poultry) and protein-rich dairy (such as yogurt) have a relatively low carbon footprint. Hence, Dairy rich diets, or diets substituting meat by dairy products are not found to yield substantial improvement of the carbon impact of the diet (Hallstrom et al., 2015).

Sources of CH_4

The CH_4 is emitted from a variety of anthropogenic and natural sources. Anthropogenic sources include fossil fuel production and use, animal husbandry (enteric fermentation in livestock and manure management), paddy rice cultivation, biomass burning, and waste management. More than 70 percent of global CH_4 emissions are related to anthropogenic activities. The remaining from natural sources include wetlands, gas hydrates, permafrost, termites, oceans, freshwater bodies, non- wetland soils, volcanos and wildfires. Emissions from enteric fermentation of the domestic livestock contribute significantly to GHGs inventories. Emissions from animal facilities primarily consist of animal respiration and enteric fermentation. In addition, emissions from manure storage are also believed to be a potential source of CH_4. Table 1 describes the sources of GHGs from Indian agriculture sector.

Table 1: GHG Emissions from Agriculture Sector in India

Agricultural Sector	**CH_4**	**NO2**	**CO2 eq**
Enteric fermentation	10099.80	-	212095.80
Manure management	115.00	0.07	2$_4$36.70
Rice cultivation	3327.00	-	69867.00
Soils	-	1$_4$0.00	$_4$3$_4$00.00
Crop residue	226.00	-	6606.00

Figures are in thousand tons

Livestock and Climate change

Livestock contribute both directly and indirectly to climate change through the emissions of greenhouse gases such as carbon dioxide, methane and nitrous oxide. Globally, the sector contributes 18 percent (7.1 billion tonnes CO2 equivalent) of global greenhouse gas emissions. Although it accounts for only nine percent of global CO2, it generates 65 percent of human-related nitrous oxide (N2O) and 35 percent of methane (CH_4), which has 310 times and 23 times the Global Warming Potential (GWP) of CO2respectively.

There are two sources of GHG emissions from livestock: (a) From the digestive process: Methane is produced in herbivores as a by-product of ‘enteric fermentation,’ a digestive process of enzymatic degradation elaborated by symbiotic microbes inhabiting in rumen medium in which carbohydrates are broken down into simple molecules for absorption into the bloodstream. (b) From animal wastes: Animal wastes contain organic compounds such as carbohydrates and proteins. During the decomposition of livestock wastes under moist, oxygen free (anaerobic) environments, the anaerobic bacteria transform the carbon skeleton to methane. Animal wastes also contain nitrogen in the form of various complex compounds. The microbial processes of nitrification and de-nitrification of animal waste forms nitrous oxide, which is emitted to the atmosphere.

The major global warming potential (GWP) of livestock production worldwide comes from the natural life processes of the animals. Methane production appears to be a major issue although it presently contributes only 18 % of the overall warming. It is accumulating at a faster rate, and is apparently responsible for a small proportion of the depletion of the protective ozone layer. Methane arises largely from natural anaerobic ecosystems, rice/paddy field and fermentative digestion in ruminant animal. In fact, CH_4 is considered to be the largest potential contributor to the global warming phenomenon, important component of GHG in the atmosphere, and is associated with animal husbandry. Much of the global GHG emissions currently arise from enteric fermentation and manure from grazing animals and traditional small-scale mixed farming in developing countries. The development of management strategies to mitigate CH_4 emissions from ruminant livestock is possible and desirable. Not only can the enhanced utilization of dietary ‘C’ improve energy utilization and feed efficiency hence animal productivity, but a decrease in CH_4 emissions and also reduce the contribution of ruminant livestock to the global CH_4 inventory.

Significance of Indian Livestock to GHG emissions: In India, although the emission rate per animal is much lower than the developed countries, due to huge livestock population, the total annual CH_4 emission is about 9- 10 Tg from enteric fermentation and animal wastes. India possesses the largest livestock population in the world and accounts for the largest number of cattle (world share 16.1%), buffaloes (57.9 %), second largest number of goats (16.7 %) and third highest number of sheep (5.7 %) in the world. Of the various livestock enterprises, dairying is most popular in the country and dairy animals, which comprise of the majority of the livestock, account for nearly 60% of these enteric emissions. The GHG emissions from the agriculture sector in India are mainly in the form of CH_4 primarily due to enteric fermentation and rice paddy cultivation. N2O is also emitted from this sector and is mainly from the agricultural fields due to application of fertilizers. Table 2 describes the contribution of different livestock species to methane pool in India.

Table 2: Contribution of Indian livestock population to methane pool

Species	Population (m)	Emission/animal (g/ year)	Population contribution Tg/year	% Contribution
Cattle	177.84	28616	5.09	54.72
Buffalo	98.70	28616	2.82	30.37
Goat	125.46	7154	0.90	9.70
Sheep	64.27	7154	0.50	5.38

(Source: INCCA, 2010)

Enteric methane emission from livestock

Livestock are produced throughout the world, and are an important agricultural product in virtually every country. CH_4 is emitted as a by-product of the normal livestock digestive process, in which microbes resident in the animal's digestive system ferment the feed consumed by the animal. This fermentation process, also known as enteric fermentation, produces CH_4 as a by- product. The CH_4 is then eructated or exhaled by the animal. Within livestock, ruminant livestock (cattle, buffalo, sheep, and goats) are the primary source of emissions. Other livestock (swine and horses) are of lesser importance in nearly all countries. The number of animals and the type and amount of feed consumed are the primary drivers affecting emissions. Consequently, improvements in management practices and changes in demand for livestock products (mainly meat and dairy products) will affect future CH_4 emissions.

Among the livestock, cattle population contributes most towards enteric CH_4 production. Enteric fermentation emissions for cattle are estimated by multiplying the emission factor for each species by the relevant cattle populations. The emissions factors are an estimate of the amount of

CH_4 produced (kg) per animal, and are based on animal and feed characteristics data, average energy requirement of the animal, the average feed intake to satisfy the energy requirements, and the quality of the feed consumed. The district or country level emission from enteric fermentation is computed as a product of the livestock population under each category and its emission coefficient. The emission coefficients for CH_4 emissions from enteric fermentation are country-specific, and these coefficients should conform to IPCC guidelines.

Enteric fermentation-Process description

Enteric fermentation is the digestive process in herbivore animals by which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the bloodstream. CH_4 is produced as a waste product of this fermentation process. CH_4 production through enteric fermentation is of concern worldwide for its contribution to the accumulation of greenhouse gases in the atmosphere, as well as its waste of fed energy for the animal. CH_4 is produced in the rumen and hindgut of animals by a group of *Archaea* known collectively as methanogens, which belong to the phylum *Euryarcheota*. Among livestock, CH_4 production is greatest in ruminants, as methanogens are able to produce CH_4 freely through the normal process of feed digestion. Ruminant animals are the principal source of emissions because they produce the maximum CH_4 per unit of feed consumed. What makes ruminant animals unique is their “fore-stomach” or rumen, a large, muscular organ. The rumen is characterized as a large fermentation vat where approximately 200 species and strains of micro organisms are present. The microbes ferment the plant material consumed by the animal through a process known as enteric fermentation. The products of this fermentation provide the animal with the nutrients it needs for survival, ena bling them to subsist on coarse plant material. CH_4 is produced as a byproduct of the fermentation and is expelled. “Monogastric” animals produce small amounts of CH_4 as the result of incidental fermentation that takes place during the digestion process. “Non-ruminant herbivores” produce CH_4 at a rate that is between monogastric and ruminant animals. Although these animals do not have a rumen, significant fermentation takes place in the large intestine, allowing significant digestion and use of plant material.

Methane producing bacteria reside in the reticulo-rumen and large intestine of ruminant livestock. These bacteria, commonly referred to as methanogens, use a range of substrates produced during the primary stages of fermentation to produce CH_4, thus creating generated energy required for their growth. All methanogen species can utilize hydrogen ions (H2) to reduce CO2 in the production of CH_4 as this reaction is thermodynamically favorable to the organisms. Availability of H2 in the rumen is determined by the proportion of end products resulting from fermentation of the ingested feed. Processes that yield propionate and cell dry matter act as net proton-using reactions, whereas a reaction that yields acetate results in a net proton increase. Other substrates available to methanogens include formate, acetate, methanol, methylamines, dimethyl sulfide and some alcohols, however, only formate has been documented as an alternative CH_4 precursor in the rumen.

The principal methanogens in the bovine rumen utilize hydrogen and carbon dioxide, but there is a group of methanogens of the genus *Methanosarcina* that grow slowly on H2 and CO2 and therefore maintain a distinct niche by utilizing methanol and methylamines to produce CH_4. Formate, which is formed in the production of acetate, can also be used as a substrate for methanogenesis, although it is often converted quickly to H2 and CO2 instead. Volatile fatty acids (VFA) are not commonly used as substrates for methanogenesis as their conversion into H2 and CO2 is a lengthy process, which is inhibited by rumen turnover. Therefore, methanogenesis often uses the C and CO2 produced by carbohydrate fermentation, as VFAs are formed. By removing H2 from the ruminal environment as a terminal step of carbohydrate fermentation, methanogens allow the microorganisms involved in fermentation to function optimally and support the complete oxidation of substrates. The fermentation of carbohydrates results in the production of H2 and if this end product is not removed, it can inhibit metabolism of rumen microorganisms.

Conclusions

The GHG emissions from the agricultural sector account for about 25.5% of total global anthropogenic emission. While CO_2 receives the most attention as a factor relative to global warming, CH_4, N_2O and chlorofluorocarbons (CFCs) also cause significant radiative forcing. With the relative global warming potential of 25 compared with CO_2, CH_4 is one of the most important GHGs. Emission of CH_4 in ruminants differs among developed and developing countries, depending on factors like animal species, breed, pH of rumen fluid, ratio of acetate: propionate, methanogen population, composition of diet and amount of concentrate fed. Among the ruminant animals, cattle contribute the maximum towards greenhouse effect through CH_4

emission followed by sheep, goat and buffalo, respectively. A synthesis of the available literature suggests that the mechanistic models are superior to empirical models in accurately predicting the CH_4 emission from dairy farms. The latest development in prediction model is the integrated farm system model which is a process-based whole-farm simulation technique. Several techniques are used to quantify enteric CH_4 emissions starting from whole animal chambers to sulfur hexafluoride (SF6) tracer techniques. The latest technology developed to estimate CH_4 more accurately is the micrometeorological mass difference technique. These informations will be very valuable in understanding the enteric CH_4 emission in depth and this understanding will help in designing suitable mitigation strategies to reduce enteric CH_4 production from domestic livestock.

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Chapter 12

Goat as the ideal climate animal model for food security

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Introduction

Livestock help in livelihood security of weaker segment of the society having poor economic sustenance with lack of resources to create favorable microclimate in terms of shelter or intensive rearing in a organized system. Global demand for livestock products is expected to double during the first half of this century as a result of the growing human population and affluence. Over the same period, big changes are expected in the global climate. Today climate change is one of the most serious long-term challenges facing farmers and livestock owners around the globe. The indirect impacts of climate change are established to be playing a significant role in reducing the livestock production. This is particularly evident in tropical countries where indigenous animals predominate. The reduction in pasture availability as well as shrinking grazing lands caused a marked reduction in livestock production. If the trend on impact of climate change on pasture availability continues, then it may cause a serious threat to livestock production. Hence, scientific communities are under enormous pressure to cope the livestock production system to the indirect impacts of the climate change. This has directed the scientific fraternity to look for the solution to sustain livestock production to ensure food security from the future perspectives. Therefore, it is very vital to channelize the research efforts to identify particular livestock species which could effectively cope with the adversities associated with climate change and produce optimally. With the projected alarming impacts of climate change on the pasture availability, small ruminants and especially goat production gain significance because of their ability to survive on limited pastures. The farming communities are looking to invest in the small ruminant livestock production systems because of their lower feed requirement, lower input cost and better climate resilience than the large ruminants. Among the small ruminants, goats are considered ideal climate animal model due to their better thermo-tolerance, drought tolerance, ability to survive on limited pastures as well as the disease resistance capacity. This compilation is therefore an attempt to collate and synthesis information on this line to project the various advantages associated with goat production to prove them as ideal animal model in the changing climate scenario.

Goat as the future animal from food security perspectives

Sustaining livestock production under a challenging climate has necessitated the need for identifying an ideal species to cater the needs of the growing human population. Several studies have identified goats as the go-to species to sustain animal agriculture under changing environmental conditions. Pioneers in livestock research had identified the potential of goats over other small ruminants to adapt to a wide range of environmental conditions. Goats are opportunistic feeders, and thus the depletion of pasture lands may hardly impose an impact their dietary requirement. Besides, the selective feeding behavior of goat helps them consume even the poor quality forages, converting the nutrients obtained into high quality products. Also, goats exhibit a bipedal stance which helps them access tree leaves which is considered advantageous as compared to other livestock species. Further, goats have a better feed efficiency than other ruminant species. Also, goats do not require specialized shelter structures and they could ideally survive in any location with minimum protection from the weather. Additionally, labor availability is another crucial factor for livestock production, but which is considered less of a big constraint in goat production since much of the labor could be done by family members.

The world's population is expected to touch an alarming count of 9.6 billion by 2050. From the food security perspectives, animal proteins are considered vital to meet the growing demands of the human population especially in the developing world. Goats are projected as the ideal climate adapted animal and are expected to perform better than other species. This projects their pivotal role in meeting the growing humanitarian needs for animal protein by the end of this century. Further, goats are also expected to perform better than other livestock species, particularly given the climate change-associated feed and fodder shortage. Therefore, researchers and policymakers should set priorities in designing appropriate programs to meet the growing human population's food demands by 2050.

In the context of the anticipated increase in human population, goats play a vital role in catering to future generations' nutritional demands through the production of milk and meat. As per the latest model prepared by Ngambi et al. (2013), dairy goats produce approximately 15.2 million tons of milk, comprising 2% of total milk production from the livestock sector. Moreover, goat meat and milk demand has been rising exponentially above other livestock species for their health benefits and therapeutic values. In harmony with this, recent reports suggest that goat enterprises have turneded out to be of more commercial value as a result of the marketing preference of goat products all over the world. With their unique ability to convert the unconventional feedstuff to high quality animal products, goats play a crucial role in eradicating poverty during disaster aversion. Thus, having the potential scope to ensure the food security, it serves as an important source of income for poor and marginal farmers around the world.

Climate resilient goat production

Sustaining livestock production in the changing climate scenario requires efforts to identify best indigenous breeds to survive in different agro-ecological zones. In series of studies conducted at ICAR-NIANP, three different indigenous breeds Osmanabadi breed from Karnataka, Malabari breed from Kerala and Salem Black breed from Tamil Nadu were compared for their climate resilience capacity. Based on several phenotypic and genotypic traits studied it was established that Salem Black breed was able to adapt and produce better as compared to Osmanabadi and Malabari breeds during heat stress exposure. The significantly lower respiration rate, rectal temperature and HSP70 gene expression in the Salem Black as compared to the Osmanabadi and Malabari groups exposed to heat stress indicate better resilient capacity of the Salem Black breed. Therefore, promoting the Salem Black breed among the local farmers may prove beneficial in improving their livelihood security. Fig. 1 describes the different indigenous goat breeds well known for the climate resilience.

Fig.1. Comparative assessment of climate resilience in different indigenous goat breeds

Concepts associated with climate resilient goat production

Given that goat production system is sensitive to climate change and at the same time itself a contributor to the phenomenon, climate change has the potential to be an increasingly formidable challenge for the development of goat sector. Currently the economic viability of the goat production system worldwide is jeopardized due to the devastating effects of climate change. Amongst the multiple climatic stresses faced by goat, heat stress seems to hugely destabilize production efficiency of the animals. The devastating effects of heat stress adversely affect the growth, meat and milk production in goat. Further, climate change leads to several vector borne diseases in goat by compromising the immune status of the animals. The animal employs several adaptive mechanisms to maintain homeostasis through behavioural, physiological, neuro-endocrine, cellular and molecular responses to cope with the changing climatic condition. Goat also significantly contributes to climate change through enteric methane emission and manure. Further, climate change can alter the rumen function and diet digestibility in goat. Hence, enteric methane amelioration is of paramount importance to prevent both the climate change as well as dietary energy loss which may pave way for sustaining the economic return from these animals. Further, various other strategies are required to counter the adverse impact of climate change on goat production. The management strategies can be categorized as housing management, animal management and monitoring of climate and these strategies are ultimately targeted to provide suitable microclimate for optimum goat production. Nutritional interventions involving season specific feeding and micronutrient supplementation may help the animal to sustain its production during adverse environmental condition. Body condition scoring system developed specifically for goat may help to optimize economic return in goat farms by minimising the input costs. Finally, sufficient emphasis must be given to develop appropriate adaptation strategies involving policy makers. These strategies include developing thermo-tolerant breeds using biomarkers, ensured water availability, women empowerment, early warning system and capacity building programmes for all the stakeholders. These efforts may help to sustain goat production in the changing climate scenario. Fig.2 describes the various concepts associated with climate resilient goat production.

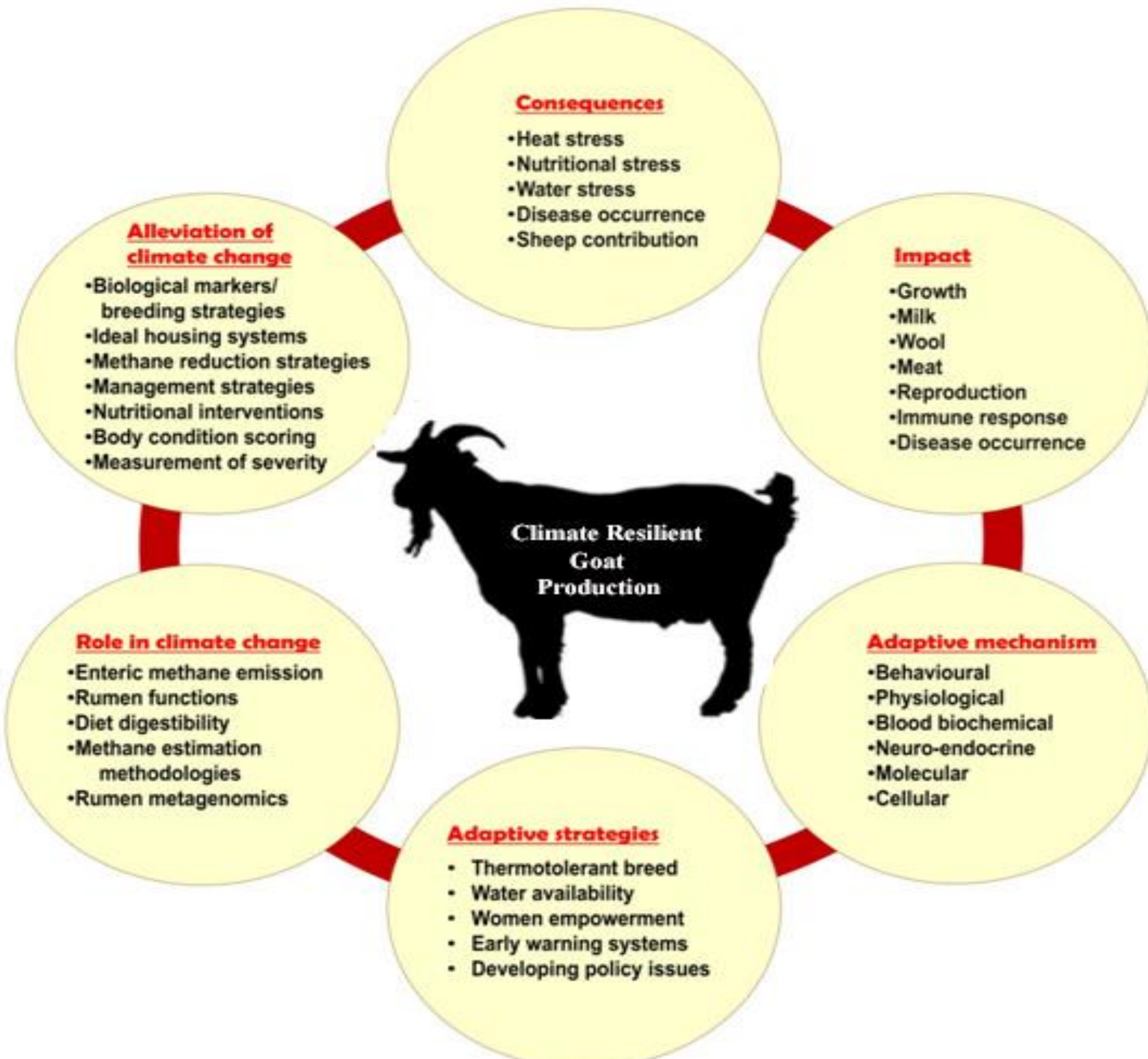

Fig. 2. Various concepts associated with climate resilient goat production

Biomarkers for heat stress in goat

Phenotypic Markers

A study conducted in Osmanabadi goats indicated that drinking frequency, respiration rate, and rectal temperature as ideal biological markers for assessing the impact of both heat and nutritional stress in Osmanabadi goats. In another study conducted in Osmanabadi goats, IGF-1, leptin, growth hormone (GH) and plasma heat shock protein 70 (HSP70) was established as the markers for quantifying nutritional stress. A study conducted to assess comparatively the climate resilient capacities of three indigenous goat breeds, Osmanabadi, Malabari and Salem Black breeds, identified drinking frequency, water intake, haemoglobin, packed cell volume, cortisol, aldosterone, tri-iodo-thyronine and thyroxin to be reliable biomarkers for quantifying heat stress response in goats cutting across breeds. These findings may be useful for assessing the effect of nutritional stress in goats and its implications for welfare.

Genotypic markers

In a study conducted on Osmanabadi goats indicated that HSP70 gene can act as ideal biological markers for assessing the impact of both heat and nutritional stress in Osmanabadi goats. In the same study, the higher expression of TLR8 and TLR10 in the heat stress group indicated that these two genes can act as the immunological markers of heat stress in goats. In another study conducted in Osmanabadi goats, growth hormone receptor (GHR), HSP70 and HSP90 were established as the markers for quantifying nutritional stress in goat. Further, in a study conducted to assess comparatively the climate resilient capacities of three indigenous goat breeds, Osmanabadi, Malabari and Salem Black breeds, indicated that heat shock factor 1 (HSF1), HSP27, HSP60, HSP70, HSP90, HSP110, thyroid hormone receptor (THR), GH, GHR, IGF-1, leptin, leptin receptor (LEPR), follicle stimulating hormone receptor (FSHR), luteinizing hormone receptor (LHR), prolactin receptor (PLR), interleukin 10 (IL10), IL18, tumour necrosis factor α (TNFα), interferon β (IFNβ) IFNγ, *Natural resistance-associated macrophage protein 1* (*NRAMP1*), superoxide dismutase (SOD), nitrous oxide synthase (NOS), TLR1, TLR4 and TLR5 can act as biomarkers for quantifying heat stress response. Fig.3 describes the different biomarkers for quantifying heat stress response in goats.

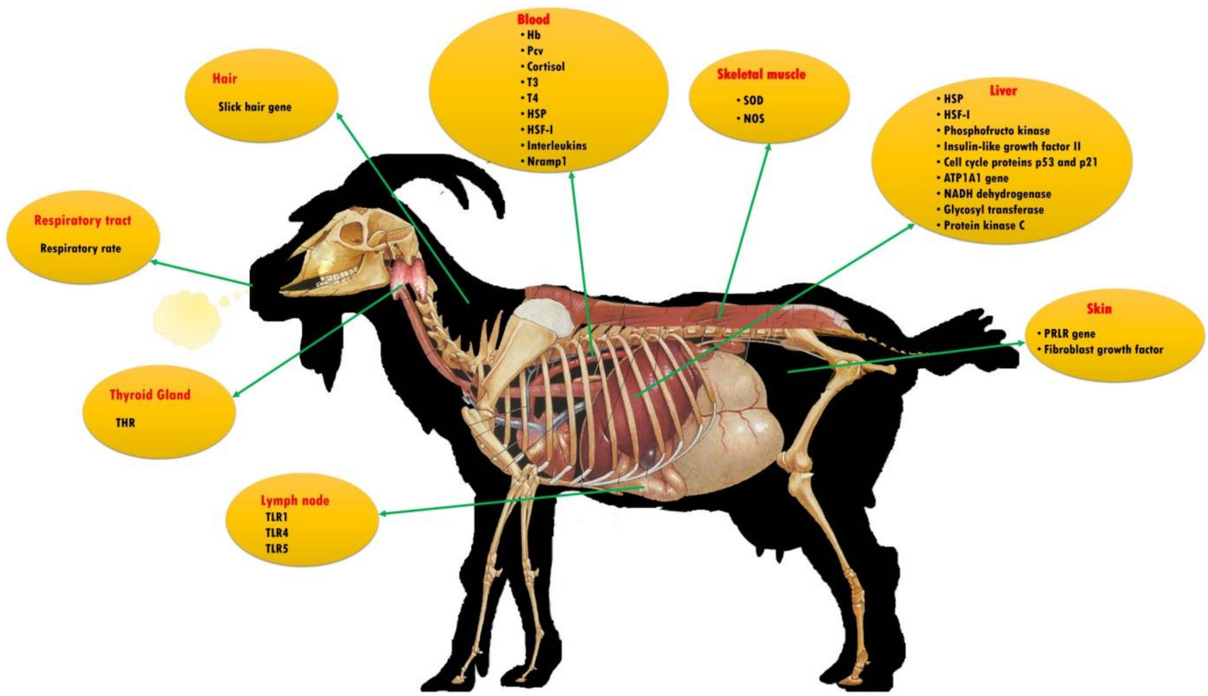

Fig.3. Different biomarkers for quantifying heat stress response in goats

Adaptation strategies to sustain goat production under changing climate

Adapting to climate change entails taking the right measures to reduce the negative effects of climate change or to exploit the positive impacts by making appropriate adjustments and changes. The highly adapted indigenous breeds identified by marker assisted selections can be used as an efficient tool for developing thermo-tolerant breeds through improved breeding programs. Promotion of such breeds can improve the production efficiency and may lead to less greenhouse gas emissions. Further, women hold rich knowledge and wide skills for maximizing the use of natural resources. Hence, occasional training and participatory research approach into the roles of women assists tackling of climate change in the rural areas. In addition, well-organized early warning systems avoid severe damages due to unexpected disasters by providing sufficient time to prepare effective response. Development of skilled disease surveillances supported with effective health services may effectively control the spread of the climate change related diseases in goat. Furthermore, improved water resource management should be developed to meet the water requirements for goat production in tropical regions. Cultivation of drought tolerant fodder varieties in extreme hot areas is an efficient adaptive strategy to ensure sufficient supply of feed during scarcity period. Finally, strengthening extension services and building awareness through capacity building programs helps the livestock keepers to improve their adaptive capacities against climate change. Adaptation strategies related to cold stress includes advanced cold tolerant breeding programs, migration in extreme winter and adoption of proper cold management practices. Hence, there is an urgent need to develop better policies and practices that ensure cost effective adaptive strategies to tackle climate change. Fig. 4 describes the different adaptation strategies to sustain goat production in the changing climate scenario.

Fig.4. Different adaptation strategies to sustain goat production in the changing climate scenario

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Chapter 13

Waste to wealth: climate resilient livestock production and product processing

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Introduction

The livestock has been an integral part of mankind for ensuring nutritional and as well as livelihood security. The global human population has been on the rise which is putting pressure on agriculture for the supply of more and more food. The arable land has been shrinking due to industrialization. Thus intensification of agriculture and livestock production has been contributing to increased emissions of greenhouse gases and in turn global warming. The increased average global temperature either through human or natural activities is known as climate change/global warming. Global warming has been attributed to the release of greenhouse gases like carbon dioxide (Co_2), methane (CH_4) water vapor, nitrous oxide (N_2O), chlorofluorocarbon (CFCs), hydrofluorocarbon (HFCs), and Sulphur hexafluoride (SF_6). The global warming potential (GWP) of greenhouse gases indicates that carbon dioxide has a GWP of one while nitrous oxide has 265-298. The GWP of methane is 28-36. The CFCs and HFCs have the highest (thousands times) global warming potential. The sources of carbon dioxide are natural (earth), human activities (fossil fuel burning and deforestation). These components augment the release of CO_2 into the atmosphere. The greenhouse gases are beneficial to some extent, however, higher levels are detrimental to our earth. The natural carbon cycle may not be emitting carbon dioxide at higher rates but human-induced (industrialization) CO_2 emission is rising at an alarming rate which is being reflected as increased average temperature and global warming. It's the responsibility of every nation and every citizen to minimize the release of carbon dioxide through reduced carbon footprints. The animals contribute 18% to anthropogenic greenhouse gas emissions. It is predicted that by the Intergovernmental Panel on Climate Change (IPCC), that within the coming 90 years the global temperatures will be increased by 1.8 and 4.0 °C (Yatoo et al., 2012). Milk and meat are important to produce in the human diet. During the production and processing of milk and meat number of solid and liquid byproducts are generated. These products need to be managed efficiently and harvest benefits for sustainable growth and development.

Waste generation

As per the World Bank, globally 2.07 billion tonnes of waste was generated in 2018 and is predicted to reach 3.4 billion tons by 2050. Further, 44% of this waste consisted of greens and food. Due to the rising demand for meat, the slaughter waste generation is on the rise and at the same time, efficient disposal of the same has been a major challenge around the globe (Kaza et al., 2018). During the slaughter of animals, a considerable amount of waste (20-35%) is generated. The nature of waste generated at different parts of slaughterhouses differs like killing floor yields blood. During dehairing, hair and dirt are obtained while paunch manure and liquor are produced. During the carcass dressing operations flesh, grease, blood, manure produced. During rendering, stick liquor or press liquor is generated. Depending upon slaughter capacity slaughter waste generation varies. The Central Public Health and Environmental Engineering Organisation (CPHEEO), Government of India (CPHEEO, 2000) categorized slaughterhouses based on slaughter capacity.

1. **Large slaughterhouses**: These have annual slaughtering capacity of > 40,000 large animals & > 6,00,000 Goats/ Sheep or daily live weight killed is > 70 Ton. The waste generation from large slaughterhouses varies from 6-7 Tons/day.
2. **Medium slaughterhouses**: Annual slaughtering capacity of such slaughterhouses varies 10,001 – 40,000 large animals and 1 lakh to 6 lakh goats/ sheep. The daily live weight killed is 15 – 70 Ton. The waste generation from large slaughterhouses varies from 2-6 tons/day.
3. **Small slaughterhouses**: Annual slaughtering capacity of such slaughterhouses is up to 10,000 large animals and up to 1 lakh goats/ sheep. The daily live weight killed is up to 15 Ton. The waste generation from large slaughterhouses varies from 0.5-1 tons/day.

During the handling and processing of milk and milk products, a considerable amount of effluent and solid waste is generated. Like slaughter waste, this effluent also has huge pollution potential. The dairy industry is also contributing to environmental pollution and a huge amount of effluent is released from processing units. It is reported that nearly 200-10000 ml (avg 2500 ml) of effluent is produced for every, one litre of milk produced (Raghunath et al., 2016).

Characteristics of slaughter waste/dairy effluent

Slaughter wastewater has huge pollution potential and therefore careful management of slaughter wastewater is essential. The properties of slaughter waste have been elucidated elsewhere (Bustillo-Lecompte and Mehrvar, 2017). In slaughterhouses both liquid and solid wastes are generated and effective disposal of both wastes is important.

Table 1. Characteristics of slaughterhouse and dairy plant wastewater

Parameter	Characteristics of slaughterhouse wastewater*	Characteristics of dairy wastewater**
BOD (mg/L)	150-8500 (3000)	1200-1800
COD (mg/L)	500-16,000 (5000)	1150-9200
TN (mg/L)	50-850 (450)	-
TP (mg/L)	25-200 (50)	8-68
TOC (mg/L)	50-1750 (850)	-
TSS (mg/L)	0.1-10,000 (3000)	340–1730

pH	4.9-8.1 (6.5)	6-11
Color (mg/L Pt scale)	175-400 (300)	-
Turbidity	200-300 (275)	-

Source: *Bustillo-Lecompte and Mehrvar, 2017 (*a value in the parenthesis indicates mean value for the particular attribute; BOD: biochemical oxygen demand, COD: chemical oxygen demand, TN: total nitrogen, TP: total phosphorus, TOC: total organic carbon, TSS: total suspended solids); ** Deshannavar et. al, 2012 & Aziz et. al, 2019.

Slaughterhouse waste management

Green technology

To protect the environment from the adverse effect of global warming, urgent steps are required. Globally several initiatives have been undertaken to minimize the GHG effect. Green technology has the potential to impact the environment positively. In green technology science and technology are used to safeguard the environment and further facilitates harmonizing ecosystem it is denoted as clean technology. It is ecofriendly technology which follows: Reduce, Reuse and Recycle. Green technology promotes less utilization of energy and helps to minimize greenhouse gas emissions and further slow down global warming. In green technology, renewable energy sources (geothermal energy, rain, wind, tides, algae, and plants) are used to minimize greenhouse gases emission, save natural resources and reduce products harming ozone.

Solid waste management

Biogas production: The slaughter of animals generates a huge amount of both liquid and solid waste. This has very high biological oxygen demand and therefore, it should be handled very carefully, or else it will cause environmental pollution, pose a risk of clogging sewerage. On the other side, this waste if utilized properly may prove beneficial, eco-friendly, and can be an additional source of income. The slaughter waste could be used in biogas production anaerobically wherein the material is converted into methane and carbon dioxide. The slaughter waste and other animal waste produce more biogas (619 dm^3kg^{-1}), than simple manure (20-30 dm^3kg^{-1}) (Hejnefelt and Angelidaki, 2009). The methane as clean energy could be used as fuel for cooking. The methane content of the produced biogas ranges 55-70%. The slurry obtained from the biogas plant could be converted into organic manure which can be used for agriculture purposes. Therefore, this approach is incredibly useful in converting waste into remarkably high-quality, value-added products and also reduce environmental pollution. Major obstacle in use of slaughterhouse waste for biogas production is higher amounts of fat which may be deleterious for acetogenic or methanogenic bacteria. Aggregation of long-chain fatty acids during the anaerobic digestion process may be toxic for the microbes. The fat also accumulates as scum during the digestion process. Therefore, biogas production from a blend of different sources may be helpful (Broughton et al., 1998; Salminen et al., 2000). This alternate fuel source could be effectively used for heat and electricity generation at the slaughterhouse. This strategy could be effective in reducing GHG emissions (Korres et al., 2013).

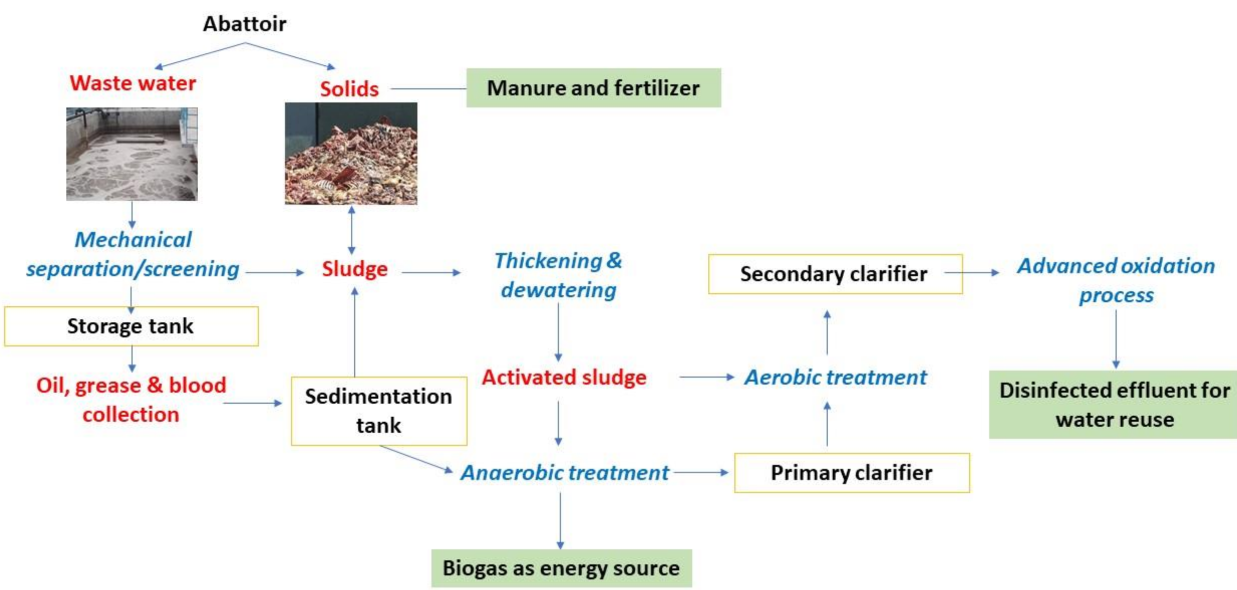

Fig. 1. Strategies for handling of slaughterhouse waste

German Federal Ministry for Economic Cooperation and Development and Sustainable and Renewable Energy Development Authority, Government of Bangladesh have jointly established pilot-scale biogas plant and are successfully producing clean energy for cooking purpose and fertilizer for agriculture from slaughterhouse waste (Talukdar, 2017). To minimize the harmful effect of slaughter waste on microbes, study, the four substrates i.e. solid waste from the slaughterhouse, manure, crop, and municipal solid waste were mixed in variable proportions to evaluate the methane production efficiency in thermophilic anaerobic batch co-digestion assays. The study revealed that when all the four components were mixed in equal parts (w/w), the highest methane yield, 655 NmL CH4/g volatile solids was obtained (Pagés-Díaz et al., 2014). The slaughter waste is more suitable for biogas production due to the more content of organic matter.

Table 2 Biogas production from slaughterhouse co-products

Substrates	**DM (%)**	**Biogas yield (m^3 per kg of TS)**
Fresh cattle excreta	25–30	0.6–0.8
Fresh sheep excreta	18–25	0.3–0.4
Poultry excreta	10–29	0.3–08
Liquid blood	18	0.3–0.6
Ruminal ingesta	12–16	0.3–0.6

(Adapted from: Afazeli et al., 2014)

Ortner et al. (2015) reported that 85% of the waste accumulated during the slaughter process was converted into 2700MWh thermal & 3200MWh electrical energy in biogas combined heat and power (CHP) plant. The energy generated by the biogas CHP-plant has the potential to meet the energy requirement of the abattoir to the tune of 50% of heat and 60% of electric demand. It was possible to 63% cost of waste disposal was saved. Further, this was eco-friendly technology as annually there was a 79% reduction (4.5 Vs 0.9 Mio kg CO_2) of greenhouse gas emissions.

Biodiesel production: The fossil fuel sources are limited therefore, it is need of an hour to search for alternative sources for the future. Global energy requirement has been on the rise. With increased industrialization, it is expected that in near future to energy demand be increased. It's been proposed that biodiesel production could be a feasible option for diesel as its ecofriendly, biodegradable, easily combustible, and renewable. The biodiesel could be produced from a variety of stuff like edible oils, inedible oils, animal fats, recycled oils, etc. The selection of substrate is very important for the production of cost-effective biodiesel. The biodiesel produced from animal fats including poultry fat is referred to as 'second generation biodiesel'. This biodiesel can be a potential solution for global energy requirements. The animal fats are subjected to transesterification to make them suitable for use as biodiesel. Studies have indicated that slaughterhouse animal fat and poultry farm animals' fats/poultry fats can be easily used for premium quality biodiesel at an affordable cost. For trans/esterification, sulfuric acid is the preferred acid catalyst while NaOH and KOH are cost-effective base catalysts. It has been observed that suitable blends of biodiesel from slaughterhouse animal fat and poultry fat with commercially available diesel elucidated satisfactory fuel attributes. The use of slaughterhouse animal fats and poultry fat could be a viable option for developing an eco-friendly fuel at a cheaper price. This would further reduce carbon footprints for a better environment (Chakraborty et al., 2014). In another study, biodiesel was produced from chicken oil obtained by dry rendering the dead layer birds. The economics of biodiesel production indicated that dry rendering followed by mechanical centrifugation method produced biodiesel@36.68/L while in case of solvent extraction method was Rs 22/L. It is been reported that blending biodiesel@20% level could minimize environmental pollution (Abraham et al., 2014).

Vermicomposting/Fertilizer: This technology is the most effective technology for the management of organic waste. Vermicomposting involves the bio-oxidation process. The organic waste is converted into valuable fertilizer through the action of microbes as well as earthworms. The vermicompost made from different sources (sawdust, city waste, sugarcane trash weed plant, pressed mud, and slaughterhouse waste) showed a Phosphorus content of 2.68–3.51% (Marlin and Rajeshkumar, 2012).

Vermicomposting is cost-effective, feasible, and user-friendly technology for efficient solid waste management. It is also useful for improving soil health and fertility. For vermicomposting, 10-35^{0}C temperature, 4.2-8.0 pH, 60-80% moisture, and 1.6 kg earthworms/m^2 area is required (Sharma and Garg, 2018). For small slaughterhouses where facilities are insufficient, and no solid waste management facility is available especially in developing nations. Such abattoirs can go for use of solid waste as manure after some processing. The use of slaughter waste for manure preparation is a lucrative proposal. Slaughter waste containing blood and rumen digesta in 1:1, 2:1, and 3:1 proportions were dried on a coal-fired earthen stove for 1.5 hrs and further mass was sundried for 3 days to obtain 'bovine-blood-rumen-digesta-mixture' (BBRDM). Its efficiency was compared with diammonium phosphate (DAP) in pot cultivation experiment by applying 5g BBRDM/kg soil second and sixth week resulted in earlier fruits by two weeks and improved fruit yield for tomato (130%), chilli (259%), and brinjal (273%). Further, there was an improvement in NPK content, microbes of soils in comparison with DAP (Roy et al., 2013). The fertilizer produced from rumen content slaughtered waste with other (tannery sludge, waxing & trimming waste, vegetable waste, coal boilers, sawdust, basalt powder, phosphorite, etc.) material. The fertilizer was applied 16 tonnes/hectare. There was improved soil fertility with increased pH, calcium, magnesium, etc. in sandy soil (Nunes et al., 2015).

Biobriquetting

The conventional energy sources are going to deplete in near future. Slaughterhouse waste like ingesta, leftover feed, fodder & other organic material are effective substitutes for coal or charcoal. The rumen ingesta and dung could be processed to form bio-briquettes. At first, ingesta and dung are dewatered followed by the addition of molasses and finally, biobriqettes are formed. It has very good calorific values of 3500 Kcal. The biobriquettes find applications in boilers of meatpacking plants for steam generation, for cooking in rendering plants, etc.

Liquid waste management

The dairy and meat industries are water-intensive units using large quantities of water and thus release large quantities of effluents. These effluents should be properly treated to prevent/minimize environmental pollution before its release. Liquid waste management involves the following processes.

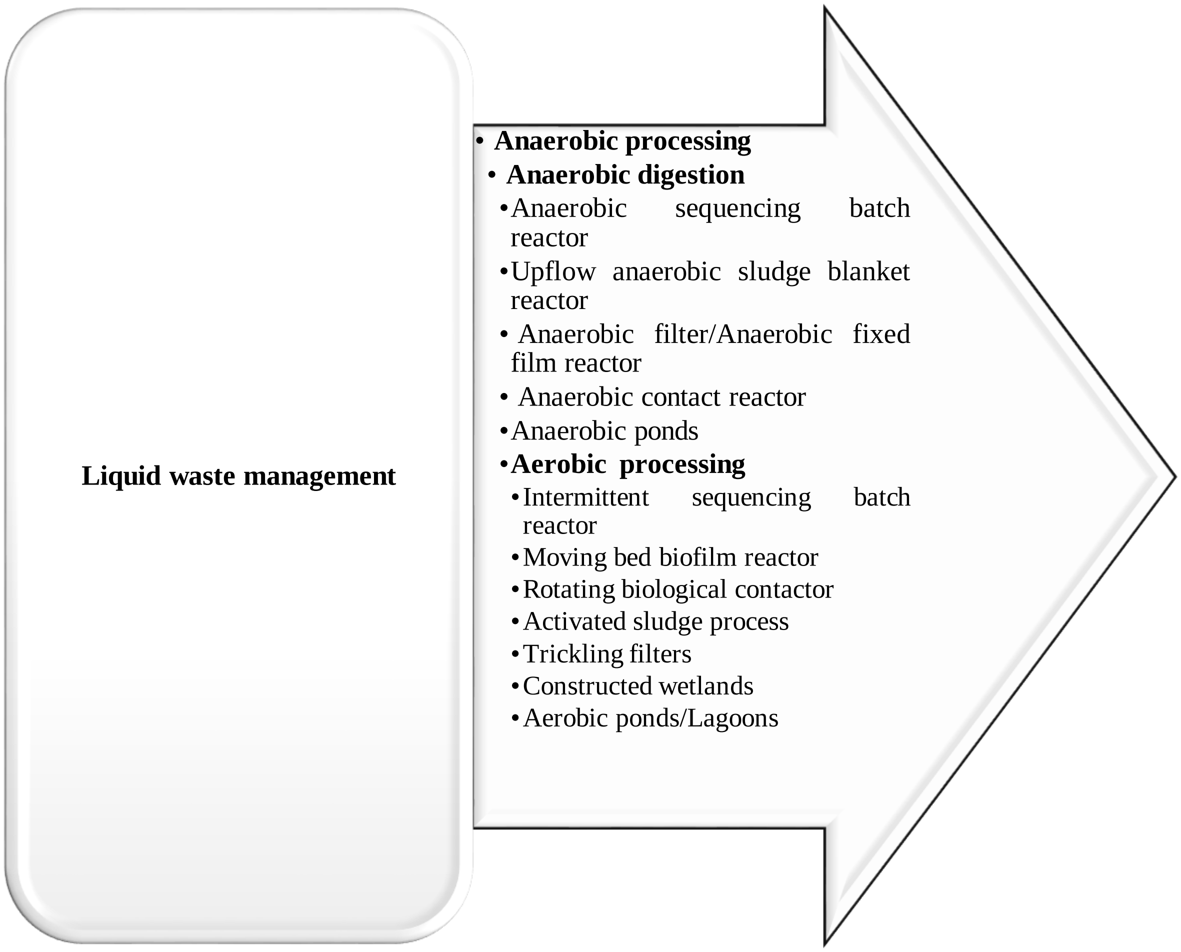

Fig. 2. Strategies for handling effluents (adapted from Aziz et. al, 2019)

A. Anaerobic process: the complex organic matter is degraded with the help of bacteria and archaea in absence of oxygen. Following anaerobic methods are used for waste management.

Table 3 Anaerobic treatment of slaughterhouse waste

Sl. No.	Processing method	Characteristics
1.	Anaerobic ponds	The covered ponds are used for biogas production. Useful where space is available. Have the potential to reduce COD by 68%.

2.	Anaerobic contact reactor	A set of reactors are assembled in the recycling process. The recycled stuff is taken to the base of the primary reactor that is an up-ward reactor. The material coming out is an aggregate of solid, liquid, and gas, therefore, a vacuum degasifier is used to isolate the gas.
3.	Anaerobic filter/Anaerobic fixed film reactor	Primarily used for slaughterhouse effluent. Steady matrix offers an attachment exterior that supports the anaerobic microorganisms in the form of a biofilm. Can be operated in upflow or downflow modes.
4.	Up-flow anaerobic sludge blanket reactor	Wastewater enters from the base of the reactor and flows upward through a layer of biologically activated sludge.
5.	Anaerobic sequencing batch reactor	Most suitable technology for slaughter effluents. Feed, react, settle, and decant all take place in succession in a particular batch reactor.

B. Aerobic processing: heterotrophic and autotrophic microorganisms degrade organic material and it is carried out in presence of O_2. As it requires higher oxygen these processes are preferred after the anaerobic process and are suitable for material having COD < 1000 ppm.

Table 4 Aerobic treatment of slaughterhouse waste

Sl. No.	Processing method	Characteristics
1.	Aerobic ponds/Lagoons	Commonly used method. In aerobic ponds, O_2 is provided by photosynthesis while artificial O_2 is supplied in lagoons. Ensures 90-95% removal of organic matter.
2.	Constructed wetlands	Simple design, economical, cost-effective, and eco-friendly. Use of soil, wetland vegetation, microbial

		groups, and all other natural processes for wastewater treatment
3.	Trickling filters/biofilter	Widely used for wastewater treatment. It is prepared with a fixed porous bed of inert material on which biofilm grows. Biofilm brings about carbon oxidation.
4.	Activated sludge process	The small quantity of biologically active sludge is mixed with screened or pre-settled effluent & agitated in presence of oxygen. The dissolved organic matter, colloidal residues & fine solids are oxidized to CO_2 and H_2O and the proteins are broken down into nitrates and sulphates by microbes in the reactor.
5.	Rotating biological contactor	Consists of parallel circular disks attached perpendicular to a horizontal shaft that passes through their centers.
6.	Moving bed biofilm reactor	It is an efficient, modified activated sludge process for the biological digestion of organic material. It contains a reactor vessel with a fluidized carrier media. Biota will inhabit the exterior and within the media, while the vigorous mixing makes the reactor self-cleaning by constantly eliminating old and ineffective microbes.
7.	Intermittent sequencing batch reactor	Suitable for removal of organic compounds and extraction of nitrogen and phosphorous. Feeding, reaction, settling and decanting all take place in one cycle.

Valuable products from waste

Bioplastics and other valuable products from sludge

Excessive use of conventional plastics is posing threat to the ecosystem and some urgent initiatives are required to protect our planet. Bioplastics are biodegradable material produced by microbes using carbohydrates and lipids. Bioplastic could be an eco-friendly and very good alternative to conventional plastic. The bioplastics have the only limitation of the higher cost compared to conventional plastic. The advantages of bioplastics are that they can be recycled and biocompatible. Polyhydroxyalkanoates (PHAs) are produced by microbes through the fermentation of carbohydrates and lipids. Renewable 'Carbon' resources from agricultural & industrial waste and/or excess activated sludge from wastewater treatment units could be used as a substrate for PHA accumulation (Chua et al., 2003). The PHAs are produced by plants and bacteria, however, increased levels of PHAs in plants have a negative impact on growth. Among bacteria, *Cupriavidus necator* is a widely studied bacteria for PHAs production. Other microbes like *Bacillus spp., Alcaligenes spp., Pseudo-monas spp., Aeromonas hydrophila, Rhodopseudomonaspalustris, Escherichia coli, Burkholderia sacchari, and Halo-monas boliviensis* are also involved in PHAs production (Verlinden et al., 2007). Sludge obtained from the effluent treatment plant is a prospective source for the segregation of microorganisms. Several different products having wide application in a diverse area like construction aggregates, adsorbents, fuels, biopesticides, bioherbicides, enzymes, bioplastics could be obtained (Klai et al., 2016).

Microbial Fuel Cell (MFC)

Microbial Fuel Cells are novel bioreactors used for the generation of electrochemical energy using exoelectrogenic biofilms. The structure of MFC consists of two chambers each containing one electrode anode (anaerobic) and cathode (aerobic). These two chambers are isolated by an ion-conducting membrane. The anaerobic microbes oxidize the substrate/organic matter and generate electrons and protons. The electrons go to an anode and pass through an external circuit and produce current while protons travel to the cathode and form water by reacting with oxygen and electrons (Sekar et al., 2019). The slaughter wastewater could be used in microbial fuel cells for bioelectricity production. The wastewater from the slaughterhouse produced a maximum power density (Pdmax) of 578 mW/m^2 (Katuri et al., 2012). In addition to electricity generation, it reduces COD levels substantially. Therefore, it could be a very important technology in the future to meet out the demand for electricity in an eco-friendly manner.

Biohydrogen production

Currently, hydrogen is produced from non-renewable energy sources which are going to finish in the near future. The microbial metabolism could be a potential source for Biohydrogen and has potential for large-scale production and fulfillment of ever-rising demand. In the future again this technology has the potential of sustainable, clean energy sources for diverse applications. For the production of biohydrogen, direct water, solar photosynthesis/biophotolysis or anaerobic fermentative process approach could be used. Out of the above mentioned technologies, fermentative hydrogen production is the most appropriate technology. Further research and developments are essential for scaling up the production in a cost-effective manner. (Mullai et al., 2013; 2016).

Waste to wealth is a lucrative option for the eco-friendly and cost-effective management of waste. Achievement of sustainable development goals is impossible without addressing waste management as every goal is directly or indirectly linked with waste management. The slaughter/dairy processing waste management is the responsibility of every processing plant. Besides containing nutrients like nitrogen and phosphorus, wastewater could be the source of energy and water. In most of the developing countries, efficient and ecofriendly management of waste is need of an hour. Besides eco-friendly, it also provides employment opportunities, clean energy, and number of very useful products with diverse applications. It is high time that slaughterhouses and processing plants must grab this opportunity and help in environmental protection by efficient management of the slaughter and processing waste. There are number of challenges also in terms of cost-effectiveness, scaling up production, more yield, etc. Therefore, research thrusts must be directed towards these goals to have a win-win situation.

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Chapter 14

Effect of thermal stress on the quality and safety of meat and meat products

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Introduction

Livestock are exposed to many forms of stress during their growth, and especially during transport to processing plants. These stressors affect the post-mortem metabolism of muscle and subsequent meat quality. Environmental temperatures play an important role in the ante mortem stress and consequently post mortem meat quality. Heat stress, chronic or acute, is one of the primary causes of stress during preslaughter activities. It can be associated with other physical stressors to animals such as crowding, transportation, and holding prior to slaughter. Any of the environmental stress factors always display increased hormonal secretion and change in the metabolites of muscle. Effects of this increase include modification of liver and muscle glycogen levels. The latter is particularly important in relation to postmortem muscle quality. The nature of the changes depends upon the severity of the stress, and the level of the animal's stress resistance at the time of death. The quality of meat results from complex interactions between the genotype and the environment, especially the stress undergone before slaughter.

Thermal stress induced carcass conditions

Extreme heat provokes an adrenergic stress response. Adrenaline stimulates peripheral vasodilatation and muscle glycogenolysis. If exposure is prolonged before slaughter the glycogen reserve gets depleted. Muscle glycogen deficiency in these animals causes a slow rate and limited extent of glycolysis after slaughter resulting in high pH_u and darker, firm, dry (DFD) meat. Pre-slaughter stressed animals have usually high temperatures, rapid glycolysis and early onset of rigor mortis in their muscles. This leads to rapid pH decline at elevated carcass temperature causing protein denaturation. The resulting exudate masks the myoglobin to give a pale, soft, and exudative

(PSE) condition. The PSE meat is associated with lower possessing yields, increased cooking losses, and reduced juiciness. Animals exercised before slaughter develops hyperthermia, the combination of high temperature and anaerobic metabolism leads to an early, stronger rigor. There is a risk that the meat could be tougher through a heat-shortening effect. Wet carcass syndrome has been a hazard in lamb carcasses when the animals have over-hydrated following dehydration during transport to abattoirs. Thermal stress also affects microbial burdens on carcasses and meat, especially if the animals carry more enteric pathogens in their gut or on their body surface.

Thermal stress on carcass quality

Swine

Among the food animals, pigs are more susceptible to changes in temperature due to much narrower zone of thermal neutrality. Pigs in hot environment had a lower final body weight and less leaf fat and back fat than pigs in thermo neutral zone. In temperate climates, pig deaths during transport and in lairage pens often increase when ambient temperatures rise. High loading densities during transport make an additional contribution to the DOA (dead on arrival) rate under hot conditions. Muscle temperature is elevated in pigs that survive the journey and have to be emergency-slaughtered on arrival at the abattoir. In these cases rigor mortis sets in earlier or is more severe. Pigs subjected to increased temperatures prior to slaughter induced a rapid rate of post-mortem muscle glycolysis, as indicated by a rapid decline in pH. Therefore pigs exposed to high temperature prior to slaughter had a more tender meat, both in fresh and cooked form, than pigs exposed to a cold environment. The pale soft exudative (PSE) condition reported in pork is one example of the negative effect of stress on meat quality. It has been reported that pigs, especially Poland China and Hampshire breeds, subjected to heat stress prior to slaughter had a higher incidence of the PSE condition**.** Pigs subjected to an increased temperature immediately prior to slaughter caused decreased meat color intensity. Poland China pigs reared from weaning to slaughter in alternating high and low environmental temperatures (repeated cycles of 3 days at 29 °C followed by 3 days 18 °C, both at 30% RH) developed paler meat compared to being reared at constant 18 or 29 °C at 30% RH. High humidities (85% RH) resulted in darker meat regardless of temperature, and they had more effect than alternating humidities (85% and 30% RH) in Landrace pigs. Water-holding capacity was lowered in all halothane genotypes due to elevated preslaughter muscle temperatures. This effect was more pronounced in pigs with Nn and nn halothane genotypes. The frequency of PSE carcasses rose from 38% when the lairage was 12 °C/90% RH, to 47% at 20 °C/90% RH and 58% at 35 °C/85% RH (Santos et al., 1997). Heat stress can also increase the frequency of carcass contamination. In pigs that had a population of ampicillin and tetracycline resistant *Escherichia coli* in their ileum and caecum, heat stress before slaughter (34 °C for 8 h or longer) increased the numbers of these bacteria in the faeces and on the surface of the carcass (Moro et al., 2000).

Poultry

Heat stress in poultry has been extensively studied, and in general, research has shown that heavier birds are more susceptible to heat and high humidity. At high temperatures, evaporative cooling is the bird's primary mechanism for heat loss; however, at high relative humidity and high temperatures, evaporative cooling is impeded thereby making it harder for birds to dissipate heat resulting in stress on the bird. The stress caused to broilers by transport to processing plants is reflected in higher transport-related mortality of the birds. Long-term trends point to an increase in death losses of broilers. Longer transport distances and transportation in summer and winter months have led to an increase in death losses among broilers transported to processing plants.

In poultry meat, the two primary factors that affect consumer acceptability are the appearance, color and tenderness. Heat stress tends to hasten the rate of post-mortem glycolysis. Hence hot season gave a more tender meat for both breast and thigh. Research finding indicated that meat from birds heat-stressed at 38°C had a higher shear value than a control group held at 20°C**.** Chickens exposed to heat stress before slaughter showed the lowest ultimate pH and birds shackled for a longer time the highest. The abdominal fat content was higher in heat stressed birds. Paler meat was found in birds that were transported for a longer time than in those after a small journey or not transported. High temperature holding just prior to slaughter may negatively affect broiler breast meat quality. Breast meat from broilers held at 29°C showed a significantly higher shrink loss, lower pH, lower cook loss, and higher shear values than that from broilers held at 7 or 18°C. No significant differences, except in yellowness (b*), occurred in meat color of broilers held at various temperatures. Muscle from broilers exhibited an increased sensitivity to acute heat stress (AHS) exposure with age. The effects of AHS on meat quality were assessed by Sandercock et al. (2001). The breast muscle glycolytic metabolism was indicated by lower muscle pH immediately post slaughter, increased water loss, and increased incidence of breast muscle hemorrhages. Values of pH were lower and hemorrhage scores greater in the AHS birds at 63 days old; drip losses were significantly higher in the 35 days old birds. Exposure to AHS did not affect breast meat eating quality, although overall reductions in flavor attributes were observed in the older birds. The effects of chronic heat stress on growth, proportion of carcass and fat deposition, and meat quality were investigated in 2 genetic types of chickens (Lu et al., 2007). One hundred and eight 5-wk-old male chickens from a commercially fast-growing strain (Arbor Acres, AA) and a locally slow-growing species (Beijing You chicken, BJY) were kept in the following conditions: constant optimal ambient temperature at 21°C and ad libitum feeding (21AL), constant high ambient temperature at 34°C and ad libitum feeding (34AL). The results showed that feed intakes were decreased by heat exposure in both type of chickens at 8 wk of age. The study also indicated that the impact of heat stress was breed dependent and that BJY chickens showed higher resistance to high ambient temperature, which could be related to their increased feed efficiency and deposition of abdominal fat under heat exposure.

In a cold-stress study, the meat from broilers held at 2°C for 2 hr prior to slaughter showed an increase in shear value. Work in Australia has indicated that retail products are more likely to carry higher total viable bacteria counts in summer. *Escherichia coli* numbers can also be raised depending on the type of product and how it is managed (Pointon et al., 2008). The turkey industry reports of substantial losses in product yield due to decreased water holding capacity during the early summer season when higher environmental temperatures are high. McKee and Sams (1997) reported chronically heat stressed turkeys exhibited lower muscle pH, higher L* values indicating paler colour, higher drip loss and cook loss as compared to turkeys grown at ambient temperatures.

Cattle

During the evolution zebu cattle (*Bos indicus*) have acquired genes that confer thermo tolerance at the physiological and cellular levels (Hansen, 2004). Cattle from zebu breeds are better able to regulate body temperature in response to heat stress than are cattle from a variety of *B. taurus* breeds of European origin. Moreover, exposure to elevated temperature has less deleterious effects on cells from zebu cattle than on cells from European breeds. Superior ability for regulation of body temperature during heat stress is the result of lower metabolic rates as well as increased capacity for heat loss. As compared to European breeds, tissue resistance to heat flow from the body core to the skin is lower for zebu cattle while sweat glands are larger. Properties of the hair coat in zebu cattle enhance conductive and convective heat loss and reduce absorption of solar radiation. In cattle, high ambient temperatures can favour greater muscle marbling and fat deposition in internal depots, in place of the subcutaneous depot (Nardone et al., 2006). However, high ambient temperatures can also lead to more dark cutting beef. In the Oman, the proportion of dark cutters ($pH_u > 6.0$) rose to almost 60% when mean daily temperature was 35 °C (Kadim et al., 2004).

Rabbits

In rabbits grown during a Mediterranean summer, a short (1 h) journey before slaughter resulted in less risk of the dark firm dry condition compared with rabbits grown in winter. However, longer journeys (7 h) during summer resulted in slightly tougher loin meat, presumably from a post-mortem heat-shortening effect (Maria et al., 2006).

Thermal stress management measures for improving carcass quality

Among the several remedial measures, increasing the spatial allocation for housing pigs may be a means to ameliorate the negative effects of temperature stress. One way pig farmers could manage summertime inappetance in pigs is to decrease the crude protein content of the finisher ration and feed higher levels of fat. This should help to offset heat-induced suppression of growth rate, and reduce the cost of the ration. High-fat diets fed in a hot environment increased pork color intensity by decreasing the glycolytic potential at slaughter and elevating muscle pH. Preconditioning broilers during their growing period to hot episodes can enhance survival to subsequent heat stress before slaughter. Transport mortality can be minimized by stocking the transport crates less densely during hot conditions, and cooling the birds with fans or sprinklers on arrival at the processing plant. Supplementation of chromium chloride and Cr picolinate at the levels of 2.0-10.0 mg/kg are equally effective in alleviating the effect of heat stress in broilers which could improve growth and carcass quality. Increased supplemental chromium resulted in an increase in body weight, feed intake, feed efficiency and improved carcass characteristics. Increased chromium supplementation decreased cholesterol concentrations, whereas increased protein concentrations in serum (Kazim Sahin et al., 2002). Dietary ethanol extracts of propolis (EEP) supplementation was found to be more effective than dietary vitamin C on growth and carcass yield in broilers under heat stress (Tatli Seven et al., 2007). Heat tolerance in cattle can be improved by introducing tropically-adapted composite breeds such as *Bos indicus* Brahman crosses, but it will lead to tougher meat through raised calpastatin activity in the meat (O'Connor et al., 1997). This can be prevented by using a heat adapted *Bos taurus* breed such as the Tuli instead of Brahman. Also use of sprinklers in hot summer can effectively reduce tympanic temperature of feedlot cattle.

Conclusions

There are severe welfare problems associated with the pre-slaughter handling and transport of animals. Increased automation of handling procedures may be one route to reducing physical damage and stress but there is evidence that movement is also a potent stressor. Substantial work also remains to be done to improve the thermal environment on the lorry. Thermal stress will increase the risk of death on arrival, PSE meat in pigs, chicken and turkeys, as well as dark cutting beef in cattle. These effects may be avoided by preventive measures such as changing the genotype or introducing better methods of cooling animals before slaughter. However, changing to heat tolerant genotypes could introduce other meat quality problems. There are concerns that rising environmental temperatures will pose a greater risk of meat spoilage and carcass contamination with *E. coli* and *Salmonella*. The higher production performance and feed conversion efficiency make today's livestock more susceptible to heat stress than ever before. Nutritional strategies aimed to alleviate the negative effects of heat stress by maintaining feed intake, electrolytic and water balance or by supplementing micronutrients such as Vitamins and minerals have been proven advantageous. Enhancing thermo tolerance by early heat conditioning or feed restriction seems to be one of the most promising management methods in enhancing the heat resistance of livestock.

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Chapter 15

Significance of balanced nutrition on immunity and meat parameters under climate change perspectives

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Among the livestock small ruminants play a vital role in the life of poor and marginal farmers. Encroachment into the forest area along with deforestation and anthropogenic contribution to climate change has affected the fodder cultivation area and their availability to livestock. This decrease in the feed and the fodder availability has affected and will continue to affect the nutrient requirement of livestock The summer season possess a great threat to the livestock as the fodder availably is much more dwindled during this period due to shortage of water requirement. It's obvious that if the energy and the protein requirement for the animals are not met, will lead to negative energy balance which father will affect the production and immunity of the animals. Grazing animals have to walk long distance for feed and water, which requires more energy and protein than the stall fed animals. The proportion of the protein and the energy supplementation to the livestock plays an key role in determining the animal's requirement, production and health level.

Compared to the large ruminants the small ruminants cope up with the adverse environmental conditions better than the large ruminants due to their adaptive capability like efficient mobilisation of fat reserves during feed restriction. Though the adaptation capability may vary with different factors like breed, age, sex etc, supplementation of appropriate and adequate proportion of energy and protein in the feed is the key to stimulate and maintain the animal under healthy immune system and for growth and production. Critical implication of the nutrients on the immune system, growth and production is an important adaptation of the animal during scarcity period as well as during high production periods. Animals with insufficient body reserves might compromise their immune system in the long run during deficiency conditions. Animal body reserve provides energy requirement by mobilizing the fat reserves from the body which in turn help the affected immune system during lean periods (Ritz and Gardner, 2006).

Similarly, the protein requirement plays a vital role in the synthesis and function of the immune system in the animal's life. Protein or the amino acids support the synthesis of T-cell- and B-cell-mediated immunity, immunoglobulins and they are catabolized for energy production (Scrimshaw and SanGiovanni 1997). Impairment in the protein availability affects the immunoglobulin production and cell-mediated immunity.

Increase in the atmospheric Co2 level and environmental temperature affects the quality of feed and fodder. The major constraint faced by the ruminants in the Asian region is due to deficiency in the availability of feed resources and nutrition (Devendra and Sevilla, 2002). Increasing demand and number of small ruminants to feed the human population, increasing desertification, along with a fall in total feed resources due to overgrazing, decrease in cultivable land, ploughing of marginal land and soil erosion, decrease in rainfall has led to a situation where, small ruminants are facing serious nutrient shortages (Salem and Smith, 2008). With large productive ruminants (Milch cattle) gaining importance in feeding along with the diminishing rangeland and water scarcity has further pulled down the feeding importance in the small ruminants, leading to deficiency of energy, protein along with other nutrients too. Under the extensive system of livestock rearing, in Indian and in the tropical regions, there is high scale of under feeding (Doreau et al., 2003), which has led to long-lasting gap between the demand and supply of protein and energy. Among the ruminants, the small ruminants are highly adaptive and are able to mobilise the body reserve very effectively during feed restriction (Atti and Bocquier, 1999). Substantial study has shown that immunity is sensitive with the availability of the nutrients (Galyean *et al*., 1999).

Energy and immunity

Energy is required by animals to perform physical activity, metabolic process, in addition they also require energy during immune response. High amount of energy is required by the animals to mount immune response. The inflammatory process requires energy, which is obtained through the process of gluconeogenesis and by fatty acid oxidation (Beisel, 1977). Increase in the energy concentration has shown positive response in poultry during higher energy intake. Negative energy balance has shown to increase in the leukocyte adhesion molecule expression, but steers supplied with decreased energy concentration had little effect in the expression of adhesion molecules (Perkins et al., 2001). Overall energy and the body reserve of the animal play a vital role in mounting the immune response, similarly animal with low energy and deficient body reserve are sensitive to the invading pathogen due to poor immunity (Ritz and Gardener ., 2006).

Hereford steers divided into three groups and fed maintenance, low energy, and higher energy diets respectively. The lower energy group showed decrease in the lymphocyte levels and plasma protein levels. Humoral antibody production response against chicken RBCs was significantly lower with atrophied thymus while they also showed elevated response to phytohemagglutinin (PHA). The higher energy fed group showed significantly lower response to pokeweed mitogen (PWM). Study conducted by Singh and his co-workers on Muzzafarnagari lambs when subjected to 100% , 80% and 70 % energy (meeting their metabolizable energy requirement) showed lower levels of differential leukocyte counts, serum cholesterol level in the 80% and 70 % energy met lambs. Delayed-type hypersensitivity response was lower ($p<0.001$), lower nitric acid production ($p<0.001$), and lower initial antibody titre to *Brucella abortus* S19 was observed in 80% and 70 % energy met group. During excess protein supplementation or during decreased energy supplementation showed increase in the somatic cell count in milk and reduced humoral immunity. Energy surplus fed pregnant heifers showed significant reduction in both CMI and HMI response (Wentink *et al*., 1997). Cows fed with high-energy diet in the last part of pregnancy were more susceptible to infectious and/or inflammatory diseases. Prolonged excess of energy could trigger a metabolic syndrome-like condition with associated inflammation in ruminants as well as in humans.

Protein and immunity

The amino acids are the building block of proteins and are required for the production of immunoglobulin, for clonal proliferation and for the immune system component synthesis. Protein deficiency affects growth development of primary, secondary lymphoid organs and tissues in addition to affecting the other organs. In general, diets that contain relatively low or high levels of dietary proteins adversely affect immunity to infection compared to diets with moderate protein levels.

Studies in relation to the impact of protein deficiency on the CMI and HMI in ruminants are scanty. Pregnant heifers fed on protein, energy deficient or both deficient for a period of two months itself-showed, significantly low levels of complement (C) hemolytic activity in low energy fed groups regardless of the concentration of protein. As the crude protein levels increased the morbidity rate of the bovine respiratory disease also increased (Galyean et al., 1999). Feeding protected condensed tannin obtained from *Ficus bengalensis* and *Ficus infectoria* to lambs and crossbred cows showed increased cell mediated immunity with high antioxidant status. Not only the protein but also the amino acids either fed individually or in combinations has shown to optimise the immune cells and their functions. Amino acids optimise the immune system by helping the intestinal function and by normalizing inflammatory cytokine secretion and improving the T cell functions, number of T lymphocyte and by increased IgA secretion (Ruth and Field 2013). Sahoo and these co-workers in the year 2009, showed that both cell and humoral immunity got altered during dietary protein alteration in sheep. However, only a few studies have examined the relationship between energy balance and immune system function in ruminants (Moyes et al., 2009). Excess of protein, energy and minerals supplementation during later stage of pregnancy and lactation causes negative effects on immune system. Protein deficiency as well as excess reduces immune function in cattle (Galyean et al. 1999). Chronic protein insufficiency - affects immune-competence of each effector- T cell. However, reports on effects of low protein diet on immune response in ruminants are scanty and a measurement of humoral or cellular immunity is very much limited. Feeding regimes markedly affected the insulin, glucocorticoid, glucagon, and IGF levels, which affect the duration and type and of immune response.

Immunity is of two types the innate immunity and the adaptive immunity. Under the adaptive immunity it is further dived into cell mediated and humoral immunity. Innate immunity has the capacity to detect and to eliminate the microbes of potential threat. The specificity of the adaptive immunity relies on their ability to identify a particular pathogen and to produce receptor specific to pathogen on the T and B lymphocytes cells through the process of gene rearrangement. B cells develop from hematopoietic stem cells of the bone marrow and matures in the bone marrow, while T cells are also produced from hematopoietic stem cells of the bone marrow but maturation occurs in the thymus gland.

Innate immune system identifies the microbial infection through the receptors called ‘pattern recognition receptors (PRRs) which identifies the pathogen based on the molecular signature patterns which are expressed only on the pathogen and not on the host, known as pathogen-associated molecular patterns (PAMPs) (Janeway et al., 1989). The name Toll like receptor (TLR) was acquired as the mutation in the receptor called Toll in drosophila led to high susceptibility against fungal infection (Lemaitre et al., 1996) and a similar homologue of Toll in human (hToll) and in mouse, currently the TLR4 was identified based on their ability to induce innate immunity (Medzhitov et al., 1997) and their failure to mount immune response against bacterial LPS respectively, confirmed their name as Toll Like Receptor (Poltorak et al.,1998).The TLRs are one among the five families that recognise the PRRs, which also includes the NOD-like receptors (NLRs), C-type lectin receptors (CLRs), RIG-Ilike receptors (RLRs), and the AIM2-like receptors (ALRs). In the last decade, though lot of work involving TLRs are present very few studies exists in relation to protein or energy availability. Of all the TLRs (1-10) all of them use the adopter Myd88 except TLR3 which uses only TIR-domain-containing adapter-inducing interferon-β (TRIF) adopter while the TLR4 uses both Myd88/TRIF adopter as a response to activation. Each TLRs are specific for their respective ligand.

Impact of protein and energy on meat parameters

The study involving the Tibetan sheep and Small-tailed Han sheep fed with diet of low-protein (~7%) and different energy yields (digestible energy, 8.21, 9.33, 10.45 and 11.57 MJ/kg) showed that the energy increased linearly ($p < .05$) with an increase in energy level in the meat while the crude protein of the meat decreased linearly ($p < .05$). On comparison between the Tibetan sheep and Small-tailed Han sheep, Tibetan sheep showed higher ($p < .1$) dressing percentage and rib eye area, while live body weight and hot carcass weight increased linearly ($p < .01$) with an increase in energy level. The Tibetan sheep meat was preferable than Small-tailed Han sheep meat, in spite of minor differences while as protein decreased and energy increased few carcass parameters and meat quality improved (Jing et al., 2020). In another experiment involving 40 growing female Salem Black breed goats was conducted at NIANP for a period of 90 day was distributed based on body weight into five individual groups: GI (n=8; Control; ICAR Recommended); GII (n=8; Normal Energy & 50% Low Protein); GIII (n=8; 50% Low Energy & Normal Protein), GIV (n=8; 50% Low Energy & Low Protein) and GV (n=8; 70% Low Energy & Low Protein). The results indicated that the 70% reduction in both energy and protein content had severe effect compared to 50% reduction on the allometric and carcass characteristics. The reduction in either protein or energy at 50% below as single component in the feed composition did not have significant effect on the primal cuts and also on the physio-chemical attributes. Carcass length, buttock width, chest circumference, chest depth, shoulder circumference, chest width and leg length did not show any variation between all the groups compared to the GI. Under the non-carcass components and offals, the feet, liver, spleen, lung & trachea and kidney in GV showed significantly ($P<0.01$) lower weight compared with the GI. Thus the study clearly points that severity in the reduction in weight of the offals were proportional to the decrease in the amount of energy and protein in feed intake emphasising the importance of adequate supply of energy and protein in the feed for the growth and maintenance of carcass, non-carcass measurement and offals.

Conclusion

Alteration in the proportion of energy and protein ratio tends to affect the immunity and meat parameters. Hence appropriate proportion of protein and energy is need for the animals to have a stable immune response and meat quality However, more research are needed to be conducted in both large and small ruminants based on age, growth, developmental stages, sex, breed and at different maintenance level etc.

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Chapter 16

Green technologies for climate resilient livestock production and processing for rural economy and in automated system

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Introduction

Food is an integral part of human life and existence. In earlier times, the human population was much smaller while resources were abundant besides there was less need for food processing and storage. As the population grew, limitations in food processing and storage techniques forced more individuals to devote a great deal of time daily to feed themselves and their families (harvesting and hunting). Industrialization forced people to have an industrialized food sector to feed the urbanized population. Population explosion in last several centuries and industrialization caused the need for sustainable food production and processing techniques have become even more relevant. At the same time, changes to climate and health of the population have made evident the dangerous balance between sustainable food production practices, a healthy environment, and a healthy population. The population growth is expected to increase to 9 billion by 2050 (FAOSTAT, 2010). Hence, adequate supplies of healthy, nutritious food will be needed to maintain global socioeconomic viability.

Therefore, there is need of ecofriendly technologies for food production. Hence, we need to resort to climate-resilient sustainable technologies for food production and processing. The industrial revolution not only increased food production but also increased waste and less efficient resource distribution. In the long run food shortages occurred which led 3 billion people to malnutrition globally with iron deficiency affecting 2 billion people and protein /calorie deficiencies heart-rending nearly 800 million people (Ferguson, 2012), and at the same time most land and aquatic resources are overused. Currently, 30-50% of food produced is wasted (Bloom, 2010). Therefore, the use of green meat production and meat processing technologies is the need of the hour not only to enhance food production and processing but also to curtail the environmental degradations and for the sustainability of the green environment. Green technology is defined by the global collaborative encyclopedia, Wikipedia, as ‘‘the application of one or more of environmental science, green chemistry, environmental monitoring and electronic devices to monitor, model and conserve the natural environment and resources, and to curb the negative impacts of human involvement’’. In the field of agriculture and agri-food, the term "green growth" is sometimes used and has been defined by the Organization for Economic Co-operation and Development (OECD) as "the pursuit of economic growth and development, while preventing environmental degradation, biodiversity loss, and unsustainable natural resource use’’(OECD,2011).

Green technologies for meat and poultry production

1. Nutrient management strategies:

Viable nutrient management approaches are essential beyond balanced ration to achieve the most proficient production system.

It is necessary to use appropriate forms of nutrients to minimize the waste and maximize the production. Customization in the form of a mineral, can radically change required inputs". "And by using the appropriate form of a mineral, excretion can be reduced by 75 percent."

2. Supplementation strategies:

Economics generally drive supplementation strategies but can be used to decrease environmental impact. Some of the approaches like using functional nutrients, the use of microbial origin supplements, tactical use of minerals and antimicrobials have potential to improve the efficiency of livestock production by up to 25 percent.

3. Sequestering waste materials:

Technologies that capture waste and convert it into energy represent new sources of income, not only in the form of the energy harvested and in the form of carbon credits.

4. Novel waste management systems:

Advanced technologies for manure handling, which include aerobic, composting, and biofilm reaction systems, have been shown in some cases to result in a 99 percent reduction in greenhouse gasses from swine production units.

5. Developing green feed processing systems

These include enzyme treatments and microbial fermentation systems. Some produce novel high-value ingredients like carbon dioxide, algae, and carbohydrates.

6. The biorefinery

The integration of different components in a biorefinery can produce less waste and produce designer feeds using natural chemistry. For example, algae, which sequesters carbon dioxide, can produce a new "crop" every five days for use as an animal feed.

7. **Enzyme and microbial biotechnology**

Biotechnological advances in enzyme and microbial technologies allows use of crop and agricultural byproducts for feedstock production. This expands the efficacy of production systems.

8. Microbial systems for detoxification

These techniques enable use of toxic feedstuff for animals, in which the material could be made useful for livestock and toxins could be removed from the feedstock.

9. Advanced monitoring technologies

Advances in analytical tools to monitor the animal health and nutrition may improve proficiency and nutrient utilization. Animal production depends on several factors like atmosphere, water, air soil etc.

Green processing technologies for meat and poultry

Supercritical carbon dioxide:

Application of Supercritical carbon dioxide in the food industry.

Commercially, supercritical fluid extraction was used in 1978 for the decaffeination of green coffee beans (Palmer and Ting, 1995). Supercritical or near-critical carbon dioxide has been successfully applied for extraction of fats and oils of fish (Zosel, 1978), beef (Chao et al, 1991), egg yolk (Froning et al, 1990), Cholesterol extraction of beef (Chao et al., 1991), milk fat (Fugimotoetal, 1987), Egg yolk (Froning et al, 1990) and fish (Hardardotti & Kinsella, 1988) and fractionation of fats and oils of fish oil (Zosel, 1978).

Electrodialysis in food processing:

In this process ionic makeup of the liquids is altered by using ion permeable layers using direct electrical potential. Upon the application of an electrical potential, these membranes will assure the transport of electrical charges via protons and hydroxyl ions produced by water splitting. These membranes may be helpful in altering the stream pH values.

Advantages of electrodialysis technology include product purification with no dilution, rapid and controlled salt removal from a product stream, efficient removal of low charged molecular species with high yield, ions substitution from adjacent solution, and pH variation and adjustment with no addition of external solutions (Boye & Arcand, 2012).

Bipolar ED in food processing: demineralization of food solutions; wine stabilization; separation of organic acids produced by fermentation; deacidification of fruit juices; production of plants protein isolates with emphasis on soy; dairy proteins; regeneration of wastewater; application of ultrafiltration–electrodialysis integrated process for the separation of peptides.Whey and molasses demineralization, tartaric stabilization of wine, and deacidification of fruit juices (Fidaleo & Moresi,2006), and production of organic acid (Pourcelly and Bazinet,2009)

Enzyme-assisted food processing:

Enzymes, have been widely used as biological catalysts in the food industry. They help to achieve desired attributes such as texture, color, flavor, and other important qualities of food materials, thus enabling raw materials and ingredients to be transformed into finished products. The use of enzymes in food processing is ecofriendly process. The foremost food enzymes include types from the oxidoreductase, transferase, hydrolase, and isomerase groups of enzymes. Examples of the oxidoreductase enzymes of importance in food processing include glucose oxidases (GOX), ascorbic acid oxidases, lipoxygenases (LOX), polyphenol oxidases (PPO), xanthine oxidase, and peroxidases. Distinguished examples of the transferase enzymes encountered in foods and food processing include the transglutaminases (TGases), fructosyl transferases (FTases), cytodextrin glycosyl transferase (CGTase), and amylomaltase. Commonly used food enzymes are the proteases, carbohydrases, lipases, and nucleases. The best-known example of an isomerase put to use in the food industry is a glucose isomerase (Boye & Arcand, 2012).

Emerging green meat processing technologies for microbiological safety of meat and meat products

Packaging Technologies:

Packaging is an essential procedure for marketing meat and meat products. The main function of packaging is to protect the packed food against environmental and physical damage, and other spoilage changes as well as to avoid contamination (Han, 2003)

Active packaging:

Active packaging depends on the interaction between packaging materials, the product, and the environment for shelf-life extension and food safety assurance (Quintavalla & Vicini, 2002). The internal environment can be controlled by substances acting as scavengers or emitters of specific gases, such as oxygen, ethylene, or carbon dioxide. Active food packaging systems are classified based on their bioactive ingredients and methods of application. Incorporating antimicrobials into sachets (containing antimicrobial agent) and absorbent pads (remove excess drip/moisture (Otoni et al., 2016; Agrimonti et al., 2019).

Intelligent packaging:

This is an innovative technology for preservation of food products. Intelligent packaging systems are designed to monitor interaction through indicators and sensors and have been commercially used as indicators of freshness, atmosphere integrity, time and temperature, and radio frequency identification (Fuertes et al., 2016). Amalgamation of nanotechnology with intelligent packaging could be a robust system for food safety management. Nanosensors can be used to detect changes in oxygen levels temperature fluctuations during storage and formation of toxic compounds as indicators of microbial growth. Some examples include the development of an oxygen gas indicator from nano TiO_2(Titanium dioxide) powder that can be incorporated in the packaging film (Liu et al, 2013) or the coupling of gold nanoprobes with superparamagnetic beads for the detection of aflatoxin M1 in milk (Zhang et al, 2013).

Nonthermal Technologies:

Consumer demands minimally processed foods with optimal sensory and other physico-chemical properties with enhanced keeping quality.

High-pressure processing:

High-pressure processing (HPP), a nonthermal food preservation technology, relies on the application of high pressure (100–1,000 MPa) for the inactivation of spoilage organisms and foodborne pathogens (Torres and Velazquez, 2005). It has been shown that HPP treatment at 600 MPa for 5 min reduced L. monocytogenes by 2 and 3 log units on the surface and interior of deboned dry-cured hams (Perez-Baltaretal, 2020).

Pulsed Electrical Field (PEF):

PEF is technology having antimicrobial effect and could be used in food processing which destroys microbes without any effect on sensory attributes of the food (Wan et al, 2009; Buckow et al, 2013). For food safety applications, electric field strengths of 20 to 50 kV/cm for 1–10 µs are necessary PEF has been proven to be a successful decontamination technology in many liquid foods, such as milk juices and liquid eggs (Buckow et al, 2013).

Pulsed light:

Pulsed light technology is another form of nonthermal technology that has been gaining popularity in recent years for its food safety applications (Heinrich et al., 2015). Pulsed light involves use of light pulses of variable wavelengths (200–1,100 nm) for little time for microbial reduction (Dunn et al., 1995). Similar to PEF, pulsed light efficacy as a preservation technology has been extensively reviewed in liquid foods (Palgan et al., 2011) while studies evaluating its antimicrobial effects on meat and meat products are limited. This technology could be used in preservation of shelf stable products by minimizing the microbial loads after packaging (Hierro et al., 2011). Findings of Hierro et al. (2011), indicated that the surface application of PL at 8.4 J/cm^2 reduced *L. monocytogenes* by 1.78 log10 CFU/ cm^2 in vacuum-packaged cooked ham and 1.11 log10 CFU/ cm^2 in bologna slices. Similar reductions were achieved for *L. monocytogenes* and *S. Typhimurium* on the surface of dry-cured meat products when pulsed light was applied at 11.9 J/cm^2 (Ganan et al., 2013).

Cold plasma technology:

Cold plasma technology is a novel nonthermal treatment exhibiting a wide range of activity against major foodborne pathogens of concern to the meat industry (Yong et al., 2017). Cold plasma technology generates reactive oxygen species, reactive nitrogen species, and ultraviolet (UV) radiation that can induce lesions on cell membranes and DNA damage (Laroussi et al., 2003). Hence, this technology can inactivate bacteria, fungi, and even viruses of food safety importance). Various methods of plasma technology have been investigated for meat decontamination (Sen et al., 2019). Exposure to dielectric barrier discharge plasma, for example, can achieve reductions of ≤0.5 log10 CFU/g for E. coli and *L. monocytogenes* in pork loins with least effect on food quality

(Kim *et al.*, 2013). Radio-frequency atmospheric pressure plasma application inactivated *S. aureus* inoculated onto the surface of beef jerky; however, inactivation was associated with longer treatment times (8 min) that increase the temperature of the food product. The antimicrobial effects of cold plasma technology on beef jerky, reporting that application of a flexible thin-layer plasma treatment for 10 min could induce reductions of 2 to 3 log10 CFU/g on microbial populations of *E. coli* O157:H7, *L. monocytogenes*, *S. Typhimurium*, and *Aspergillus flavus* (Yong *et al.*, 2017).

Irradiation:

Irradiation is eco-friendly and safe technology for production of safe food but narrow consumer acceptance is limiting use of this technology. In meat industry, irradiation was used for restricting the *L. monocytogenes* in ready to eat meat products during refrigerated storage (Sommers et al., 2000). Normally, ionizing radiation of 1 to 10 kGy could be used and a dose of 3KGy have potential to minimise E. coli O157:H7 and L. monocytogenes by 3 log units in beef sauasages with keeping quality of 12 days (Badr, 2005).

Ultrasound technology:

It involves use of sound pressure waves having frequency more than 20 kHz. It brings about chemical changes in microbial cell membranes and produce free radicals (Chemat et al., 2011). Ultrasound treatments at high intensity, above 1 W/cm^2, with frequencies ranging between 20 and 500 kHz have been successfully used for decontamination of juices and fresh produce (São José et al., 2012). Although in infancy, the prospective of high-power ultrasound for decontamination application in meat and poultry products have been explored (Haughton et al., 2012).

Use of ultrasound alone has inconsistent results. In a recent study, it has been shown that ultrasound treatment of 20.96 W/cm^2 for 120 min effectively inhibited E. coli O157:H7 in brine solution but failed to minimise pathogens on beef (Kang et al., 2017). However, improved antimicrobial efficacy of ultrasound has been reported by other authors when used in combination with steam marination, or lactic acid solutions (Birk and Knøchel, 2009).

Thermal Technologies:

It inactivates pathogens by using steam and hot water during processing of meat and meat products; with conduction of heat from source to the thermal centre of meat. It takes more time and uneven heating of meat products while more cooking time causes alteration in sensory attributes and loss of heat sensitive nutrients (Mckenna et al., 2006; Wang et al., 2009).

Ohmic heating/ electrical resistance heating:

Uses passing of alternating electric current through the food to produce heat due to the electrical resistance offered by the food. Ohmic heating causes microbial inactivation due to the thermal effects which abolish the bacterial cell membrane and enzymes in the food products (Sun et al., 2011). In addition to thermal inactivation, ohmic heating results in the phenomenon of electroporation, i.e., the formation of pores in the microbial cell membrane which leads to leaching of cellular contents (amino acids, nucleic acids, and proteins) ultimately leading to cell death (Knirsch et al., 2010).

High-frequency heating:

Radiofrequency heating.

It conveys direct heat to the food by converting electrical energy into heat energy in the food itself (Guo et al., 2006). It can pierce up to 200 mm into the food, confirming even heating in food matrix (Altemimi et al., 2019). Radiofrequency cooking (27.12 MHz and 6 kW radiofrequency oven power) of beefsteaks to 65°C produced 5-log reduction of *E. coli* O157:H7, O26: H11, and O111 (Rincon and Singh, 2016). Radiofrequency heating (500 W, 80°C, 33 min) and reported 5.3 and 6.9 log_{10}CFU/g reductions in *B. cereus* and *C. perfringens*, respectively, in pork luncheon rolls (Byrne et al. 2010).

Microwave heating:

This process is extensively used in homes; but has an inadequate industrial application for improving the safety of meat products (Stratakos and Koidis, 2015). Microwave heating at 80°C for 1 min eradicated *E. coli O157: H7* in beef (Huang and Sites, 2010). Microwave heating (1,100 W at 2,450 MHz) of frankfurters for 75 s can minimise *L. monocytogenes* by up to 3.7 log10 CFU/cm^2 (Rodríguez-Marval et al., 2009). Non-uniform heating is a problem in microwave heating resulting in the growth of bacteria. Therefore, combined use of microwave heating in combination with microwave-assisted pasteurization system or microwave-assisted thermal sterilization (MATS) to produce safe food has been emphasized (Soni et al., 2020).

Other Emerging Technologies:

Organic acids:

Lactic and acetic acids are most widely used organic acids to minimise the occurrence and number of pathogens. The spraying in a spray cabinet is most common, nonetheless immersion may also be used (EFSA CEP Panel, 2018). The effectiveness of antimicrobial activity is determined by type of the product, microbial load, bacterial contaminants, and ability to form biofilms (Koutsoumanis and Skandamis, 2013). Nevertheless, time temperature combination (DeGreer et al., 2016) plays an important role in efficacy against pathogens.

Peroxyacetic acid:

Peroxyacetic acid (PAA) fits a class of manmade chemicals known as organic peroxides. The greater oxidizing capacity and low pH of PAA confirms its antimicrobial power. The advantage of PAA is, its wide pH and temperature range and is effective in presence of organic matter, also it's free of any untoward effect on meat quality. It can be used for carcass rinsing or spray chilling (Cap et al., 2019). It has been indicated that spraying PAA on hot carcasses is more effective (Han et al., 2020), but findings on the effectiveness of PAA are inconsistent and varies with concentration, carcass portion, application technique, time, and phase of processing (Thomas et al., 2020).

Electrolyzed oxidizing water (EOW):

EOW is generated by electrolyzing water and salt in an electrolysis chamber in which saline solution separates into alkaline and acidic EOW. The alkaline EOW, being strong reducing may be used as a substitute for detergent (Cheng et al., 2012). The acidic EOW has strong oxidation reduction potential thus having antimicrobial activity (Al-Holy and Rasco, 2015). EOW does not require transportation, storage and handling issues. The antimicrobial activity is lost rapidly if not incessantly generated due to the evaporation of chlorine (Cheng et al., 2012).

Ozonation:

Ozone is an allotrope of oxygen with strong oxidative properties against both gram-positive and gram-negative bacteria (Kalchayanand et al., 2019). The two main methods to generate ozone are photochemical (UV) and corona discharge and UV is the most applicable in the food industry

(Brodowska et al., 2018). The use of ozone is promising since it does not leave chemical residues, can be used for wide range of foods, and is comparatively safe for the environment (Pandiselvam et al., 2019).

Essential oils:

Essential oils are plant-based products that have shown a wide range of antimicrobial activity against spoilage and pathogenic microorganisms (Liu et al., 2017). The antimicrobial effects of essential oils come from their major bioactive compounds (e.g. Terpenes: thymol and carvacrol or phenylpropanoids: cinnamaldehyde and eugenol) with antimicrobial efficacy varies with the composition and concentration of mixtures of bioactive compounds as well as the species and strain of the target microorganisms (Efenberger-Szmechtyk et al., 2021). Due to adverse effect of essential oils on sensory attributes of meat products, use in a hurdle technology with less concentrations can used (Jayasena and Jo, 2013).

Bacteriocins:

Bacteriocins are natural antimicrobials agents produced by the bacterial ribosome with bactericidal or bacteriostatic activity against closely related microbial species (da Costa et al., 2019). Bacteriocins generally show a wide spectrum of activity against gram-positive bacteria but may require impairment of the outer membrane by other methods before they can be effective against gram-negative bacteria (Castellano et al., 2017). Lactic acid bacteria are the most studied bacteria as it is used in food. The bacteriocins could be used either by direct addition or in-situ production by using bacterial strains (da Costa et al., 2019).

Conclusion

Use of green technologies from farm to fork is a promising option for ecofriendly and sustainable production. Use of combined technologies may be useful by adopting hurdle technology concept. Additionally, the success of the application of these technologies to enhance meat safety relies on research demonstrating enhancement of safety of meat and meat products without compromising quality, responding to consumer concerns, and offering perceptible advantages of meat processing technologies. Green meat production and meat processing technologies are the need of the hour not only to enhance food production and processing but also to curtail the environmental degradations and for the sustainability of the green environment.

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Chapter 17

Impact of climate change on livestock: mitigation and adaptation strategies

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Introduction

In recent years, the global community is overly concerned about greenhouse gas (GHG) emissions and climate change because food security could be at stake. Recent projection says livestock plays a critical role in achieving food security, and its demand is expected to increase by 70% by 2050. Pertaining to the source of emissions, livestock accounts for 7.1 gigatonnes of CO_2 equivalent in global GHG emissions. Livestock does matter to climate change. Ruminant methane (CH_4) emissions are not only an environmental threat but also cause 10-11% of productivity loss, which cannot be simply overlooked. That's precisely why we need suitable mitigation and adaptation strategies in place to counter the GHG emissions and climate change at large.

Sources of greenhouse gas emissions

The three primary greenhouse gases in the atmosphere are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Enteric fermentation is the second-largest source of methane emissions, accounting for 40% of total emissions (Fig.1). Cattle release the most enteric CH_4 (77%) followed by buffalos (13%), and small ruminants (3%). At the same time, manure storage and processing also emit about 10% of the sector's CH_4 and N_2O emissions.

Also, there is a close link between productivity and emission intensity in ruminant production. Higher CH_4 emissions per unit of consumed energy are caused mainly by poorly digestible fibrous rations. Enteric fermentation is the primary cause of emissions in low-productivity regions. On the contrary, in developed regions feed production and processing, as well as manure, are all significant sources of pollution, as enteric fermentation. When we talk in terms of emissions per protein, beef has the highest emission rate, followed by meat and milk from small ruminants. The global average emission intensities of cow milk, chicken products, and pork are considerably lower.

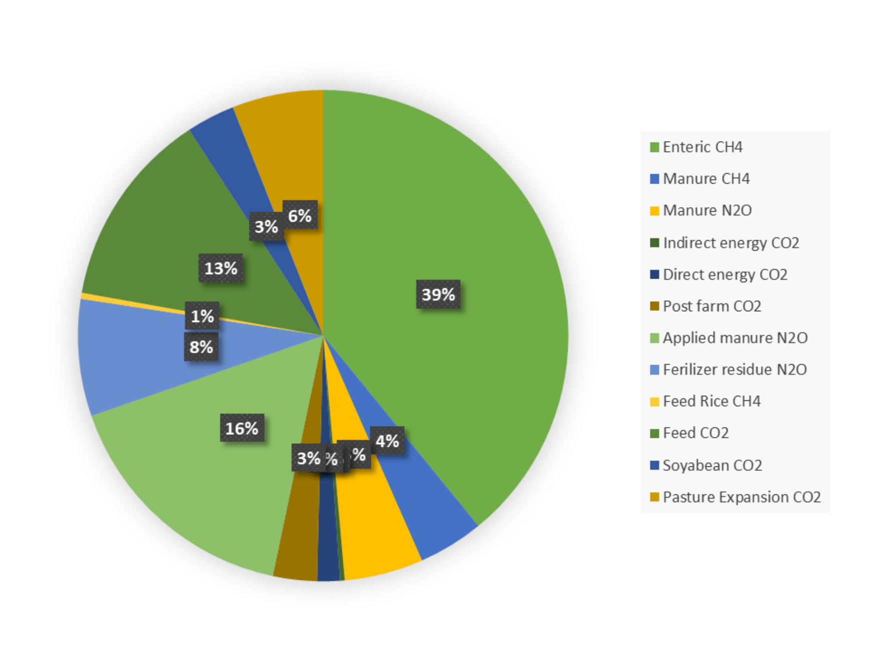

Fig 1.Categories of emissions from the livestock supply chain.

Impacts of Climate Change on Livestock Production

Significant negative impacts of climate change (CC) on livestock production have been reported as depicted in the table.1 which is primarily due to reduced voluntary feed intake during heat stress. Quantification of such impacts in absolute terms is necessary to get a better picture of the magnitude of change in production levels that will in turn aid the policymakers to make an informed decision while formulating strategies to counter climate change.

Table.1 Direct and indirect impacts of CC on livestock production

Direct impact	Indirect impact
Retardation of animal growth	A decline in quantity & quality of feedstuff like pasture, forages, grains, etc.

Low-quality animal products like hide & skin	Increase in livestock disease
Reduction in milk production & conception rate	Increase in livestock Pests

Mitigation Strategies to Reduce Enteric Methane Emission

The three key GHGs released by livestock production systems were N2O, CH4, and CO2 denote losses of nitrogen (N), energy, and organic matter that stifle productivity. As a result, possible emissions-reduction interventions are largely focused on technologies and practices that increase animal production. Adoption of mitigation practices/ technologies that improve production efficiency is critical as they can reduce trade-offs between mitigation, food security, and livelihood of the livestock farmers. Various strategies are at hand to mitigate enteric methane emission like management strategies, feeding strategies, rumen manipulation, etc.

Management Strategies

Reducing ruminant livestock population, breeding, and manure management are all management techniques that could be used to reduce methane emissions. The most effective methane mitigation technique is to reduce the ruminant livestock population. Increased livestock productivity, which may allow for fewer animals to produce the same amount of output while emitting less enteric methane. Genetic selection and breeding of low methane emitters are some of the breeding management strategies that could be used to reduce methanogenesis. Also, Manure management techniques like reducing manure storage time and supporting anaerobic digesters may significantly reduce CH4 emissions.

Feeding Strategies

Improving the productivity and efficiency of livestock production by improved nutrition is the most promising approach for reducing methane emissions from livestock. This involves techniques enlisted in the table.2 such as increasing concentrates in the ration, improving pastures, processing feed, and so on. Methane emissions are reduced by changing the roughage concentrate ratio of ruminant rations by increasing concentrates. However, increasing concentrates raises lactic acid production, which could lead to ruminal acidosis. Another effective way to reduce enteric methane emissions is to improve pasture quality. Mixed pastures, such as alfalfa-grass pastures, have been shown to minimize emissions by 25% compared to grass-only pastures since leguminous forages increase digestibility. Likewise, feed processing techniques such as ensilaging, chaffing, and grinding have been reported to reduce emissions by 10% can also be exploited for reducing enteric CH4 emissions.

Table 2.Techniques available for mitigation via feeding practices

S.No	**Technology/Practices for enteric methane mitigation**
1.	Inclusion of concentrates
2.	Usage of better quality forages & grazing management
3.	Forage processing
4.	Precision feeding
5.	Manipulation of rumen using direct-fed microbial, bacteriocins
6.	Feed additives like ionophores, nitrates, Tannins

Rumen Manipulation:

Inclusion of ionophores (monensin, lasalocid, salinomycin), bacteriocins (Nisin, BovicinHC5), dietary fats, organic acids (malic & fumaric acids), probiotics (yeast culture), prebiotics, nitrates, sulfate, halogenated methane analogs (Bromochloromethane, Chloral hydrate), and secondary plant metabolites (tannins & Saponins) are possible intervention strategies as depicted in Fig 2. to bring down the enteric methane emission. Reducing hydrogen production by inducing acetogenic bacteria, defaunation (removal of protozoa), and vaccination (to reduce methanogens) are some techniques studied extensively but not operational in field conditions yet.

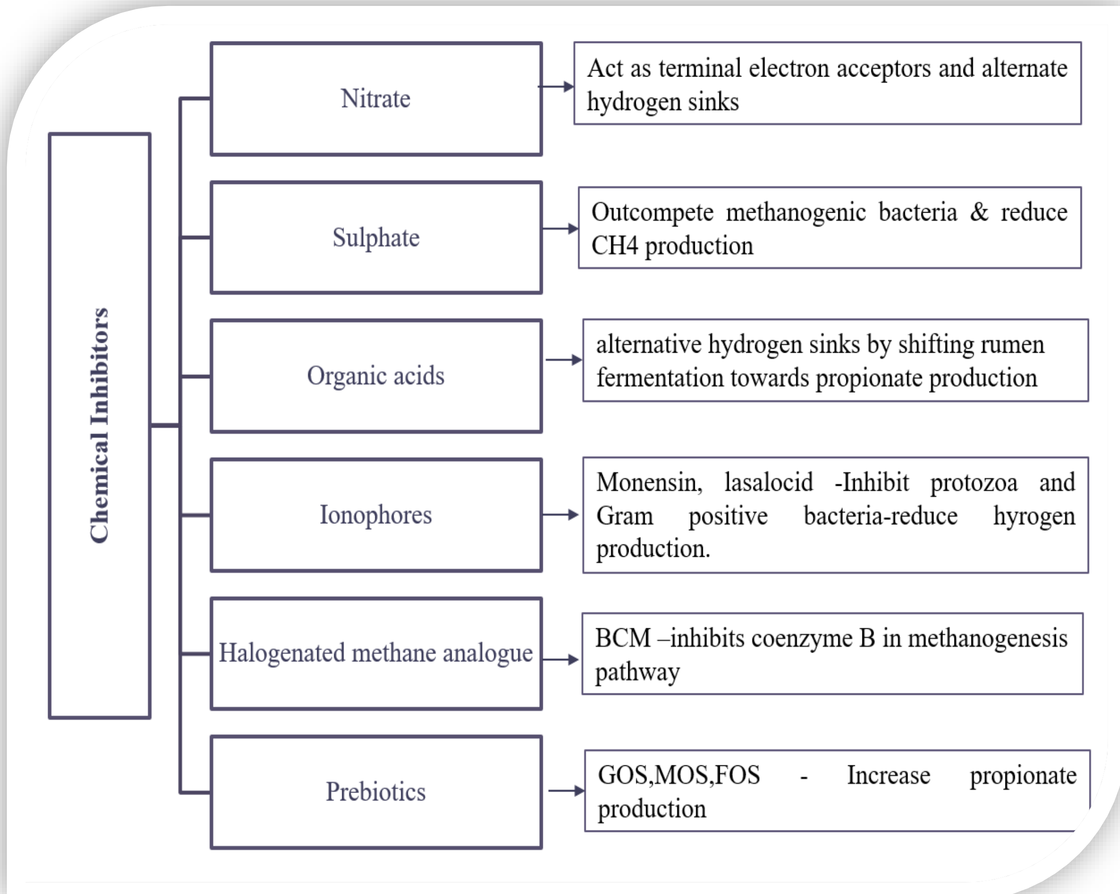

Fig 2.Enteric CH4 mitigation strategy for livestock using chemical inhibitors.

Manure management practices

Manure management has a lot of potential for reducing GHG emissions from livestock. There are many strategies as listed in table 3. like shortening storage time, trapping biogas released in anaerobic conditions are some successful ways to reduce GHG emissions from manure.

Table 3.Techniques available for mitigation via manure handling

S.No	Technology/practices	Mitigation strategy
1.	Dietary manipulation	Reduction of high fibre diets
2.	Housing	Provision of biofiltration system, manure system
3.	Manure treatment	Solid separation, manure acidification, anaerobic digestion
4.	Manure storage	Reduced storage time, composting, litter stacking
5.	Manure application	Time of application, soil cover

Adaptation Strategies for livestock in the face of climate change

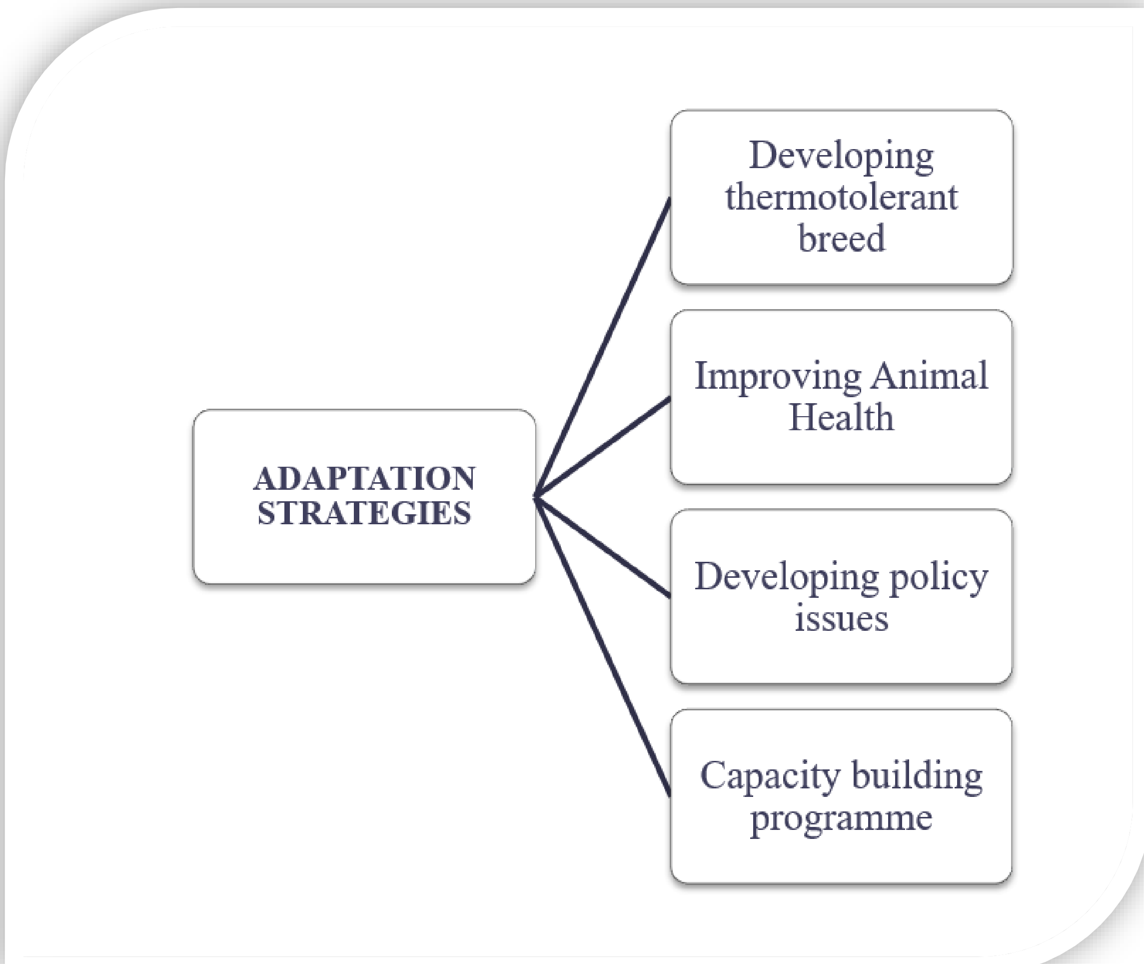

Fig 3. Adaptation strategies for livestock to combat climate change.

- Recognize and strengthen local breeds that have already adapted to deal with local climatic stress, as well as cross-breed with thermotolerant breeds to boost local genetics.
- Improve animal health by putting in place effective and sustainable animal health services, bolstering the surveillance with GIS, and improving the animal disease control and prevention system perhaps the much-needed adaptation strategy.
- Realize the livestock sector's adaptation potential and promote its long-term growth, by formulating some supportive policies and strengthening the institutional frameworks. Adaptation and mitigation measures that serve both growth and environmental goals must be prioritized by policymakers. As a part of regulations, mitigation goals should be assigned for livestock sectors, as well as more prescriptive measures such as mandating the use of particular mitigation and adaptation technologies and practices.
- Develop suitable capacity-building strategies that can help with the conversion and use of readily accessible more effective technologies and practices. This could be done by creating awareness on CC, how to combat climate change impact on production, and by providing access to improved technologies and the ability for their implementation by training the concerned stakeholders on such agroecological technologies/practices.
- Efforts should be made to ensure that current regulations at the regional, national, and international levels by providing greater financial incentives to reduce pollution from the livestock sector, by introducing abatement subsidies, or by imposing an emissions tax, etc. among other measures.

Conclusion

Climate Change is a major threat to sustainability in the livestock production system, where mitigation and adaptation strategies play a major role to reduce GHG emissions from livestock. Mitigating enteric methane emissions in ruminants will assist not only in achieving the international commitments and also in improving the energy utilization efficiency and the performance of livestock. Both these mitigation and adaptation strategies should go hand in hand if we intend to sustain the livestock production under the changing climatic conditions. Any effort to mitigate the effects of climate change must take a multidisciplinary approach, by roping in relevant disciplines like animal nutrition, health, and housing. In all likelihood, the uncertainty issue regarding the nature and extent of the impact on the production level should be addressed right away so that Government/policymakers can devise appropriate policies accordingly. To increase the availability and affordability of effective mitigation options, significant research and development are needed. Therefore, continued research on suitable breeding programmes, exploitation of the genetic potential of native breeds, genetic antagonism that exists between adaptation and production traits, simulation models are warranted to cope with the changing climate scenario.

Suggested readings

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