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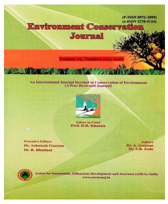

Technology driven livestock farming for food security and sustainability

Zahoor A Pampori ✉

Division of Veterinary Physiology, Faculty of Veterinary Sciences, SK University of Agricultural Science & Technology- Kashmir, Alusteng, Srinagar, Kashmir, J&K., India

Aasif A Sheikh

Division of Veterinary Physiology, Faculty of Veterinary Sciences, SK University of Agricultural Science & Technology- Kashmir, Alusteng, Srinagar, Kashmir, J&K., India

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ABSTRACT

Advent of industrialization increased the human population significantly and it expanded very rapidly from nineteen sixties. Introduction of mechanization, chemical fertilization and genetic selection in agriculture increased the food production, reduced pestilence and thus improved life expectancy. However, in doing so the natural resources were over utilized, degraded and polluted. The greenhouse gas emissions from anthropogenic activities increased several folds that resulted into global warming, the consequences of which are being observed in the form of floods, draughts, cloud bursts, melting of glaciers, rising of sea level and loss of species. The soil fertility & water table is decreasing, resistance to pesticides, drugs, antibiotics is increasing and immergence & reemergence of diseases are common. Since the world population by 2050 is anticipated to touch 9 billion that means an increase of 30%. Obviously, the demand for food to feed such a huge population would require 70% increase in the food. With limited resources, depleted soil, polluted atmosphere, disturbed ecosystems and exhausted natural resources, the challenges for food security have amplified. Urbanization, improved incomes and dietary changes will increase the demand for food of animal origin in coming years. Globally animal products provide 67% of the protein and the requirement for meat and milk by 2050 is expected to increase by 73% and 58% respectively. Therefore, to ensure food and nutritional security in coming years, livestock production has to be augmented efficiently, smartly and sustainably. As such, precision, smart livestock farming is inevitable that must integrate all the techniques, skills, knowledge and innovations to produce safe, sufficient, affordable, accessible and sustainable animal food with minimum environmental impacts. With the advancement in robotics, biosensors, artificial intelligence, internet of things and information technology, the farming practices should now be technology driven, smart, need based, automated, productive and integrated.

Introduction

Technology as we understand is an album of techniques, methods, skills, and processes in the production of goods and in present case the production of safe, sufficient, nutritious, affordable, accessible and sustainable food for human consumption. Technology required for food security depends on country, culture, literacy, physical environment, climate, infrastructure, economic conditions and governance. Various technologies are involved in increasing the food production that include land preparation, management of soil and water, production of seed, management of farms and livestock, control of diseases, harvesting and post-harvest management like storage, processing, packaging, marketing and distribution. Mankind has been endowed with natural resources like land, water, soil, forest, climate, biodiversity that provides food security,

Corresponding author E-mail: *drzap64@gmail.com*
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nutritional security and of course ensures good health. Agriculture includes arable farming, horticulture, forestry and livestock that are committed to produce food, fiber, forest products, horticultural crops, and their related services, using natural resources for sustaining life. With the rise of sedentary human civilization, the era of agriculture dawned some thousands of years before (Stephens *et al.*, 2019). The gathering and eating of wild-grains began at least 105,000 years ago. Animal agriculture, the livestock has a history of domestication of sheep between 13,000 and 11,000 years ago (Herren, 2012), followed by cattle and pigs some 10,500 years ago (McTavish *et al.*, 2013). Bocquet-Appel (2011) stated that hunting and gathering alone could not have sustained increasing human population but the progress in agriculture enabled the humans grow several folds. With the British Agricultural Revolution in 17th century, the global population rose significantly and since 1900, the mechanization, use of chemical fertilizers, pesticides and selective breeding in agriculture in developed nations increased production of food several folds to feed growing population. The increased food production lead to ecological, environmental, political and economic concerns like water pollution, depletion of resources, climate change, degradation of soil and loss of species diversity. These issues were acknowledged globally and concept of sustainable agriculture was incubated and sustainable development goals (SDGs) were launched by global forum UNO. Sustainability does not mean to reduce production but increase the production with judicial use of resources and their conservation. In order to have sustainable food production, we need to adopt modern technologies, stress tolerant, climate resilient, smart, efficient cultivars/ breeds, along with use of automation, robotics, IOT, and information technologies to push the production curve up to feed ever increasing human population.

Food and nutritional security scenario

More than 11% of global population (811 million) regularly go to bed hungry. Some 193 million people suffer acute food insecurity. About 5,70,000 people are facing catastrophe, starvation and death in 4 countries (FAO, 2022). The main drivers of this global hunger on top are conflicts/wars followed by economic shocks and weather extremes. Moderate to severe food insecurity has been climbing slowly for last few years and 30% of the world population is affected. India that stands 2nd largest populated country has 17% of world population and is home to 194 million people who go to the bed hungry every day. India stands at place 101 in a list of 116 countries of global hunger index with hunger score of 27.5 (Fig. 1; Pampori, 2022). India has the highest burden of neonatal deaths, 45% U5M because of under-nutrition. India's children are amongst the most malnourished in the world, with stunted- 35.5%, wasted- 19.3% and underweight – 32.1% (NFHS-5) as against global average of 22%, 6.7% and 12.6% respectively (Fig.2; Sila Deb, 2022). The malnutrition in children has serious implications of reduced birth weight, lowered resistance to infections, increased neonatal mortality, poor learning and cognitive abilities, poor school performance, reduced work productivity which ultimately results into human capital & economic loss of a country (Pampori, 2021).

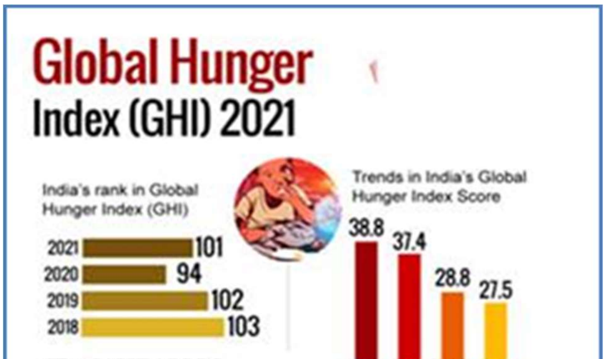


Fig. 1.GHI - 2021

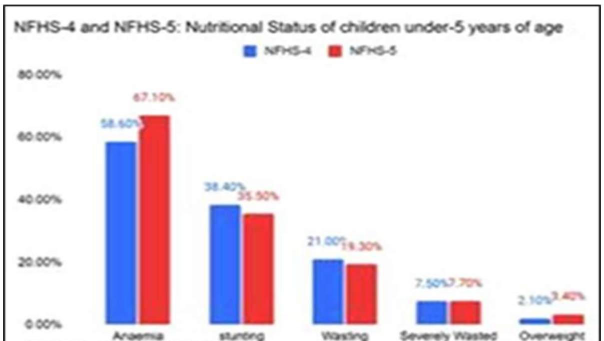


Fig. 2. Hunger index indicators

Livestock in food and nutrition security

Livestock is an important component of State economy and it contributes 40% of global agricultural GDP and provides over 33% of the world's protein intake and 7% of global kilocalorie consumption. Livestock provides food and nutritional security through meat, milk and eggs. These animal products have high quality proteins with essential amino acids, besides they provide fats and fatty acids, minerals, vitamins, small quantities of carbohydrates and other bioactive components. The demand for food of animal origin is increasing with urbanization, improved incomes and changing dietary preferences. The per capita meat consumption is 42.1 kg/year, a global average, however it goes as high as 82.9 kg/year in developed countries and 31.1 kg/year in developing countries. Milk on the other hand has global per capita consumption of 108 kg per person per year that is below the FAO recommended 200 kg/capita/year consumption. Milk is consumed either as liquid or cheese or milk powder or cream. Malnutrition is common in some poor countries that do not sustain the minimum required levels of meat and milk. The demand for meat and milk in 2050 is expected to swell up by 73 and 58 percent, respectively, from their levels in 2010 because of population growth. About 9 billion human population is expected by 2050 and providing food security to such a huge population will be a great challenge for agriculturalists. Therefore, the priority for livestock producers will be augmenting production, processing and marketing of safe and affordable meat and milk.

Growth in livestock sector in independent India

India has achieved a rapid growth in protein of animal origin through white, red, blue and silver revolution after independence. There has been 287% increase in milk production, 1120% increase in egg production, 147% increase in meat production, 22000% increase in culture fish and 358% increase in capture fish production from nineteen eighties to 2020 in India (Pampori, 2021). The average meat consumption in India stands at 4.5 kg/capita/year as against ICMR recommendations of 11 kg/capita/year, milk consumption of 154 kg/capita/ year and 100 eggs /capita/year against recommended 287 ml of milk and 180 eggs/capita/year. The fish consumption in India stands at 4-5 kg/capita/year as against global per capita fish consumption of above 20 kilograms a year (FAO, 2016). Despite huge increase in production of food of animal origin, the Indian State still has home for hungry people (14% of population). The requirements of protein are being fulfilled by livestock products, however, the availability and accessibility to the livestock products is limited, that leads to hunger and malnutrition.

Strengths & challenges in livestock sector in India

India has 2.3% of global land and 17% of global population and 11.70% of world livestock population (Islam *et al.*, 2016). India has rich animal genetic resources and wide diversity of 50, 17, 34 and 44 breeds of cattle, buffaloes, goats and sheep respectively (NBAGR; http://14.139.252.116/agris/breed.aspx). However, India is a home to high proportion of low yielding indigenous livestock having 51 % of the cattle non-descript with average milk production of 550 kg per lactation, first calving at 4 years and calving interval of 20-24 months. Similarly, 36% buffaloes are non-descript with very low genetic potential (Prakash, 2021). The poor animal management and care further deteriorate the production, only 30 % of the breedable animals are bred through AI & 70 % through natural service with AI success rate is only 40%. India has 86% of farmers with small livestock holdings of 2-5 animals. Above all, lack of strict and effective breeding policy for domestic livestock in India has remained a big lacuna in livestock sector. In-fact Indian dairy sector is characterized more by 'Production By Masses' than 'Mass Production'. 20% of total milk is handled by the organised sector and 20% equally shared by Co-operatives and Private dairy organizations (Fig.3; Vora & Vishwanath, 2020). 46 % of milk produced is retained by the households or sold to non-producers in the rural areas whereas 54% of the milk in the country is surplus for domestic marketing (Prakash, 2021). Similarly, meat sector in India is not an industry but serves as a supplementary and complementary enterprise with a huge gap in demand and production of meat. Meat purpose breeding is negligible in India that doesn't give boost to meat production. 1% of the total meat produced in the country is used for processing and 99% marketed fresh and hot carcasses. The quality of meat is poor as animals used for meat are spent animals and sold through local retail shops with no basic facilities for different operations and little awareness about meat hygiene besides inadequate infrastructure. There is dearth of abattoirs and processing plants, besides abattoirs lack basic amenities for hygienic slaughter and proper utilization and disposal of byproducts.

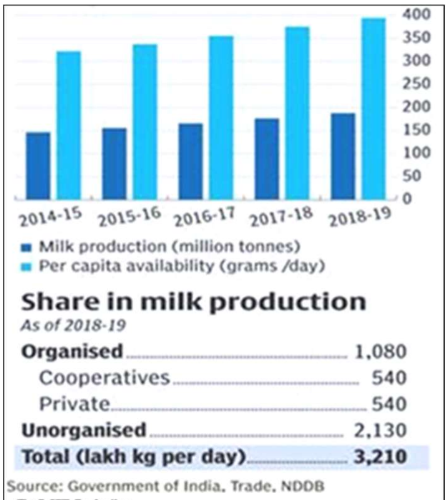


Fig. 3. Milk Production

Technology interventions in food security

In order to have food & nutritional security of large human population, livestock sector in India needs special attention of researchers, industry and policy makers so that production of food of animal origin is augmented significantly, efficiently, sustainably and made available, accessible and affordable through use of technologies and innovative practices – smart livestock farming. The various technologies available need to be roped-up, integrated and applied in livestock sector to have nutritional security. Use of digital technology, big data analysis, robotics and block-chain technology can be a game changer in the livestock sector. Some of the technological interventions in livestock sector to augment production are briefly discussed in present article under various headings.

Biotechnological interventions

Biotechnology is primarily the use of techniques and tools in animals, plants or microorganisms or their parts to produce or modify the products or to improve their characteristics for upkeeping the demands of human beings. Biotechnology has influenced many fields like agriculture, livestock and veterinary, industry, food sciences, pharmaceuticals and medicine. Biotechnology has become an effective and a vital tool for the development of a country world over. This technology requires regulatory policies to avoid threat to biodiversity, human health, the environment and ethical issues (Nguyen & Ly, 2018; Chekoland Gebreyohannes, 2018).

Animal biotechnology provides new and quick opportunities for genetic improvement in the production of farm animals. It can be used in promoting growth, increasing growth rates, improving nutrient intake efficiency, augmenting milk production, fecundity, hair, and fiber, reducing environmental impacts, imparting disease resistance and augmenting reproductive performance (Nguyen & Ly, 2018) (Fig. 4).

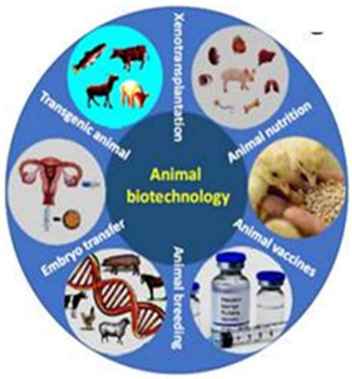


Fig. 4. Spectrum of animal biotechnology

Artificial insemination, *embryo transfer technology, cryopreservation, transgression, transgenesis, gene editing, embryo splitting, cloning* are some of the biological techniques employed in livestock for augmenting production. Artificial insemination and embryo transfers have remained two important techniques in animal breeding to improve the genetics of production traits. Artificial insemination technology supports development of high merit progenies in terms of production, reducing the number of breeding males, minimizing the venereal disease transmission and provides gender choices. While AI exploits male genetics, embryo transfer technology exploits female genetics also with production of high genetic merit embryos and transferring them in surrogates. (Wheeler, 2013; Murray and Maga, 2016). *Semen sexing* technology has provided an opportunity to produce progeny of the desired sex, either male or female. DNA polymorphism evaluation through restriction fragment length polymorphisms (RFLP) and randomly amplified polymorphic DNA (RAPD) are reliable techniques to estimate the genetic uniqueness of populations that can be exploited for increasing genetic makeup of livestock for production traits, disease resistance, etc. (Yadav *et al.*, 2017).

Molecular-assisted breeding, a new molecular technology will change the traditional approach of phenotyping to genotyping. The genomes of domesticated livestock viz. chicken, pig, cow, sheep, and horse etc. have been completely sequenced (Bai *et al.*, 2012) and employment of molecular techniques will assist in selecting animals for desired traits.

Genomics and Marker-Assisted Selection (MAS) techniques are used in discovery and identification of DNA sequences associated with important animal traits referred to as molecular markers and has applications in trait improvement, heritability determination, and product traceability.

Molecular marker-assisted introgression (MAI) technique enables and guides livestock breeders in selecting individuals that are expressing the introgressed gene. Marker-assisted selection can be used to augment beneficial traits in livestock like controlled growth rate, disease resistance, heat and cold tolerance, lower cholesterol in eggs, and an increased lean-to-fat ratio in pigs. The use of molecular markers reduces the time incurred in selection and identification of the desired individual in contrast to conventional method of several backcrossing cycles. In livestock trait improvement, molecular markers are now being used for important traits like growth, meat and wool quality, milk quantity and quality, and disease resistance. Use of molecular markers by regulatory bodies serves as an important tool in ascertaining product quality and food safety. It is also a useful technique in identification and tracking livestock parentage and its products from field to the slaughter house and from carcass to the kitchen.

Somatic cell nuclear transfer (SCNT) technology has revolutionized the field of reproduction and reproductive biotechnology. The technology has been employed in producing clones of high merit animals and has also greatly facilitated the transgenic modification of animals. Cloning technology through SCNT will help livestock farmers to replicate animals of high genetic value as a seed-stock. The SCNT technology can be used to assess the interactions of genotype v/s environment efficiently. Transgenesis has opened an effective window of using transgenic farm animals as biological factories to produce high value products or pharmaceuticals or hormones in their milk and is known by "Gene Farming". Transgenic technology involves inserting of a desirable gene or set of genes from one animal species to another to get them expressed in transgenic animal in their production system and many genes for hormones, pharmaceutical peptides have been constructed and engineered to get expressed in the milk of mice, rabbits, sheep, goats, swine, and cattle. Similarly, micro-organisms have been used to produce hormones or pharmaceuticals in bulk through this transgenic recombinant technology, the best example is of *E. coli* that has been transgenically modified with the genes from a cow to produce bovine somatotropin hormone (BST), injections of which in dairy cattle enhance milk production. C1 inhibitor and antithrombin, produced through gene farming are now commercialized (Bosze and Hiripi, 2012). Transgene for lysine biosynthesis into a pig genome, or lysostaphin in cows have been expressed to eliminate supply of lysine in pig ration or resistance to *Staphylococcus aureus* in cow to reduce mastitis.

Research in omics like genomics, transcriptomics, proteomics, glycomics, metabolomics, pharmacogenomics, toxicogenomics and ionomics are seen as the future important target areas in future drug designing or personalized medicine. The omics research would become exceptional tool in understanding diseases and developing new drugs (Dunisławska *et al.*, 2017). Omics can be implemented in improving traits of production and abiotic stress tolerance, enhancing resistance to pests and diseases and improved product quality. Omics can be helpful in the understanding patho-physiology of livestock diseases, thus providing opportunity to improve the livestock health and production. Technology driven livestock farming will be taking advantage of the developments in molecular biology, biotechnology or bioengineering to speed and scale up the development of highly productive and healthy animals. *CRISPR-Cas*

technology offers great opportunity to reap the rapid changes in economic traits of any living organism including livestock. It presents a window to modify existing characteristics or incorporate novel traits into an organism within a short period of time. Genes that negatively regulate the economic traits can be silenced/ knocked down using CRISPR technology with considerable success rates. Increasing muscle mass in animals has been achieved by introducing CRISPR-based mutations in myostatin genes (Firdous, 2021).
The advanced biotechnological tools and techniques are effectively used in pathogen detection and characterization in infected hosts that facilitate early detection of diseases and their effective control. *The recombinant DNA* technology, is being now employed in the production of effective vaccines and the diagnosis of infectious diseases and their prevention (Nascimento and Leite, 2012). In recent years, recombinant DNA technology has been used widely in the food, dairy, and brewing industries through modification of genetic material of bacteria, yeasts, and moulds. Recombinant technology and protein engineering has been used to develop novel enzymes with modified structures for thermal stability, substrate specificity, or the ability to work under extreme conditions (Gurung *et al.*, 2013). Metabolic engineering, an important biotechnological tool, is in offering to produce valuable metabolites or natural secondary compounds in large amounts that are otherwise difficult to extract and purify from their natural sources. The technology is available for the production of antibiotics, vaccines, vitamins, enzymes, and other useful bioactive products that improve the animal health and consequently their production (Tang and Zhao, 2009).

AI, IoT, ML, Robotics & ANN

Artificial intelligence (AI), internet of things (IoT) and machine learning (ML) have been inviting the attention of agriculturalists and livestock managers to make a breakthrough in livestock management. The technology involves connecting of biological and environmental information of livestock obtained by IoT sensors, storing the data in cloud, analysing, diagnosing and changing it into simple and valuable information through artificial intelligence, making informed decisions and subsequently relayed to the farmers or automatically controlled system for effective implementation (Fig. 5). Sensors record the physiological parameters of every single animal, AI diagnoses possibility of disease and accordingly informs the farmers, and farmers can take timely necessary care of the livestock. This helps to improve production efficiency and reduce physical labour and labour cost. It can be a best innovative intervention in transforming every field of livestock. It will equip the farmer with forecasting skills of the highest grade for prompt prediction of disease outbreaks, timing of various livestock practices - “Smart cow-house”. It will enable farmers to improve the quality, quantity of livestock products and ensure their timely marketing. Through IoT & AI technology, farmers can formulate rations depending upon the production, functional state, weather, environment, behaviour of livestock and available resources. IoT-AI-ML technology can be mobilized for improving farm economy through prediction of customer preferences, precise prediction of shelf life of products to reduce the post-harvest losses. Blockchain technology is one more sensitive technology that ensures and guarantees traceability of animal products from farm to fork, thus providing a dynamic system of disease outbreaks monitoring and consequently preventing the related economic losses and food-related health pandemics. Use of robotic milking machines, automatic calf feeders or brushes for added cow comfort in dairy farms can make farming smart, efficient, more profitable, sustainable and green. For small farmers, use of robotics, drones, sensors and radio imaging technology may be very helpful in Indian conditions. Brainwired is an Agritech startup based

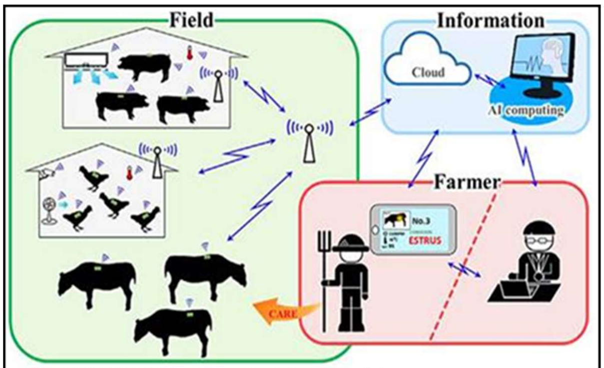


Fig. 5. IoT & AI driven livestock farm model

out of India, which has developed a livestock health monitoring, and tracking system named “WeSTOCK”. This digital system uses the AI & IoT technology to record all the activities of individual animals, body temperature, behaviour besides environmental physical parameters and then through computing, predicts reproductive cycles, disease or sickness. Remote sensing technology, global positioning system (GPS), geographic information system (GIS), satellites can now be integrated and used in assessing the needs of livestock thus can help in efficient & sustainable utilization of resources, reducing the input costs with efficient production. The automated milking system was developed and commercialized in 1992 and De Koning (2010) reported that the automated milking system can manage larger herds with less physical labour and labour cost. Mastitis can be detected using AI & IoT technology with milking machines and in-line monitoring for automatic milking system can reduce the chances of mixing of contaminated milk with whole lot of safe milk thus minimising the economic loss (Hassan *et al.*, 2009; Steeneveld *et al.*, 2010). Farmers can now provide animals with feeding mixtures and amounts tailored specifically to their needs or at least tailored to a herd or group using automated feeder systems. While employing the AI-IoT-ML technology we need to put continuous efforts to refine the exactness of measurements, requirements as well as focusing on physiological and biological considerations. The employment of AI-IoT-ML technology demands a closer coordination and a methodological linkage among livestock /animal, engineering and computer sciences. Similarly, use of automated cleaning systems in smart farms will help to remove waste and runoff from animal sheds, be it a pen or stall, and move it to a pile. The cleaning technology will reduce disease occurrence and shall create a cleaner environment for the animal besides minimising the contact of farmers with the waste.

Innovative interventions in reducing post-harvest losses and animal waste to wealth

i. Use of Apeel - A natural ingredients obtained from plants help in maintaining the quality of agricultural produce and greatly reduce food, water and energy waste during its sojourn from farm to kitchen. Since consumers are now more health conscious so the chemical preservatives are not liked, therefore, safe, organic alternatives are to be introduced in preserving food products.

ii. Cold sterilization - Maintenance of cold chain to prevent the post-harvest losses will be an effective measure to increase farm income, reduce environmental issues and sustain natural resources. Presently available cold storage capacity in India is less than the half of the required, only 29.7 million tons cold storage capacity as against 61.7 million tons (Pampori, 2021). Similarly, the transportation system in India is not much effective and needs more efficient, automated and programmed. Studies have shown that farmers have low price realisation and there is a huge wastage in the supply chain due to fragmentation, poor storages, inefficient information flow (Pingali *et.al*., 2019).

iii. Waste to wealth/ Circular bioeconomy - Circular bio-economy minimizes the leaks of energy and materials from the system by re-cycling them in production with alternate uses of food waste. The projections of 30% increase in human population by 2030 with more liking for processed foods will result into production of large amounts of agro-industrial by-products which could become an environmental burden. Therefore, the technologies of feed processing and manufacturing that can utilize the increased share of by-products or waste in livestock feeding will be promoted and needed. The livestock intensification that can be the only way to provide food security to increasing human population has resulted into production of huge amounts of animal manure. Animal manure on other side is associated with production of green house gases and source of parasites and pathogens which could lead to environmental issues and water pollution. Thus the introduction of appropriate management technologies that could mitigate the health and environmental risks associated with the overproduction of organic wastes will be welcome step. Composting and vermicomposting have become the two best-known environmentally appropriate technologies for the recycling of manures under aerobic conditions (Bernal *et al.*, 2009; Domínguez and Edwards. 2010), by transforming them into safer and more stabilised products (compost and vermicompost) that has huge application in agriculture to increase soil fertility and hence production. Technologies like biogas fermenters are being employed in recycling and recovering nutrients and energy from animal waste thus reduce environmental pollution. Anaerobic digestion reduces the risk of water pollution from manure slurries and also improves human/farm cohabitation in rural regions by reducing odour emissions by 70–95% (Massé *et al.*, 2011). This process has other direct advantages of biogas production as renewable energy and the fortification of mineral fractions of N and P during digestion (Insam and Wett, 2008), resulting in a more balanced nutrient mix for plants as compared to undigested manure thus helps in more food production(Lied *et al.*, 2006) (Fig.6)

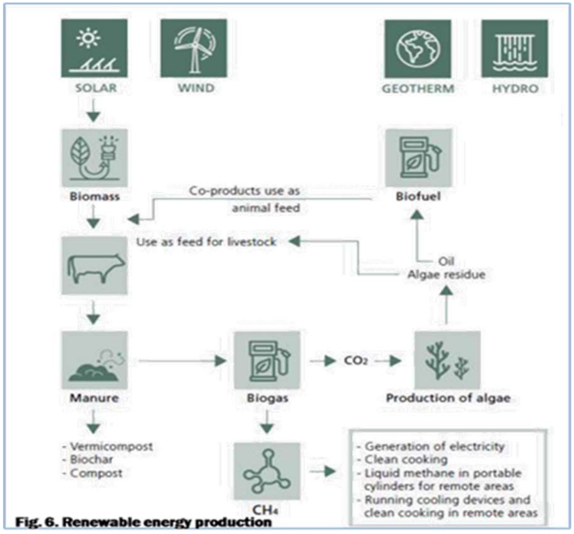


Fig. 6. Renewable energy production

iv. Slaughter house solid waste disposal - Solid waste generation is an alarming global issue associated with considerable rise in population, industrialization and urbanization. This waste has a tremendous pressure on the environment and public health and creates several environmental (water, air, and soil pollution) and health issues (waterborne diseases and respiratory illness), besides contribute 3% of global greenhouse gas emissions (Tahir *et al.*, 2015). Presently, the solid waste generation is estimated to be about 11.2 billion tons per year worldwide which is estimated to increase to 19 billion tons per year by 2025 (UNEP, 2021). Generally, slaughterhouse wastes are animal byproducts that remain unutilized after slaughtering and it has been estimated that about 30% to 50% of the total weight of slaughtered animal remains as slaughterhouse waste in livestock and poultry industry (Adhikari *et al.*, 2018; Meeker, 2009) that are well-recognized drivers of GHGs.The rising population and increased liking for animal foods ultimately increases the abattoir waste especially in urban areas. The management of wastes from slaughterhouses becomes a huge challenge that needs to be accounted for. In India, almost 3/4th of budget allocated to urban solid waste management is utilized for waste collection and transportation with little actually left for the effective treatment of solid wastes (Lahiry, 2019). Segregation of organic wastes collected from slaughterhouses or abattoir shops or centralized markets from other inorganic waste fractions is the main issue with solid waste disposal. As such mechanized slaughter houses with modern, hygienic processing units and efficient mechanism of slaughterhouse material collection, segregation, utilization and disposal is priority.The wastes from slaughterhouses and abattoir shops have huge potential for energy and product recoveries like protein hydrolysate synthesis, enzymes, and lipids. However, proper collection and treatment is of prime importance in order to harvest their maximum potency. Alonge (2005) has estimated that about 50–54% of each cow, 52% of each sheep or goat, 60–62% of each pig, 68–72% of each chicken, and 78% of each turkey is utilized for meat and the remaining is disposed off as waste. The slaughterhouse waste is majorly comprised of rumen (80%), dung/manure (12%), blood (5%), and others (3%) by weight (Fig. 7). The slaughterhouse waste disposal is through conventional methods of dumping, land filling, composting or incineration, however, anaerobic digestion is environment friendly and more valuable as it produces renewable energy. The slaughterhouse waste is produced in huge quantities and is increasing every other day, therefore some innovative technologies are always welcome in this sector to reduce environmental and health issues arising from the waste and at the same time increases the economy through its utilization. The slaughterhouse and poultry wastes are growing renewable energy resources and the production of renewable energy from such wastes will reduce the fossil fuel share in total energy supply and resultant reduction in carbon dioxide emissions. Therefore, research focussed on eco-friendly and sustainable energy from waste biomass is necessitated to replace conventional fossil fuels (Demirbas *et al.*, 2009). Since both these wastes are rich in protein content, hence could be an ideal substrate for biofuel production. Several new innovative technologies have been researched and adopted and need to be strengthened. The few are described hereunder.

Biodiesel production Biodiesel is a green diesel, renewable energy, a replacement for petroleum diesel derived from animal fat, plant and vegetable oils through transesterification of long chain fatty acids producing methyl, ethyl or propyl esters.

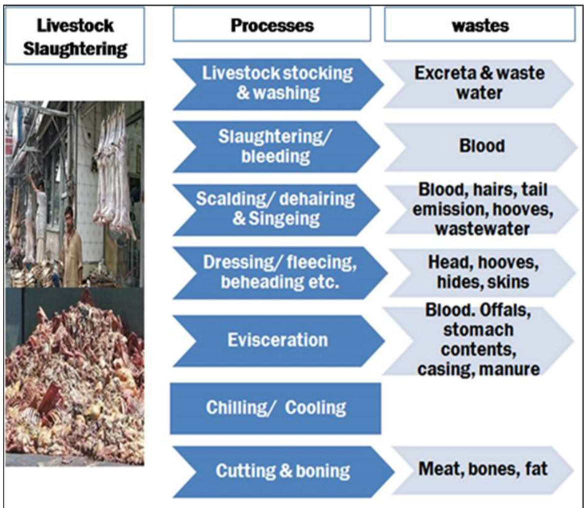


Fig. 7. Livestock slaughter processes & waste

These biodiesels can be blended with petroleum diesel or used in pure form as a renewable energy source. Further, the glycerol that is by-product of the trans-esterification process, can be used as a potential raw material for the synthesis of various chemicals, biodegradable polymers and also for energy production (Ashby *et al.*, 2009). Processes involved in biodiesel production from animal waste are shown in Fig. 8. Therefore, the technology of biodiesel production from slaughterhouse material can prove a vibrant technology in coming days reducing dependence on fossil fuel with resultant lower GHG emissions.

Pyrolysis: A process of thermal decomposition of organic wastes in absence of oxygen in a controlled environment also termed as devolatization. During the combustion at high temperature the organic waste is reduced to stable solid carbon residue called as bio-char that can sustain in soil for

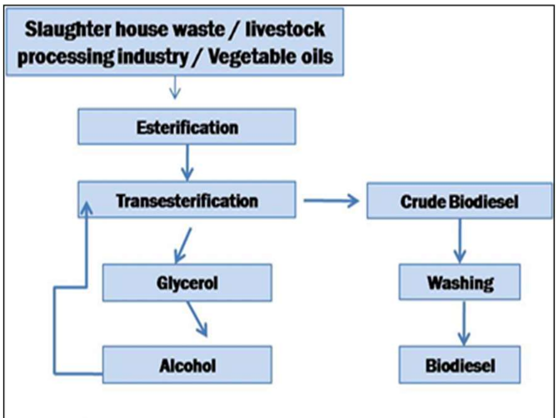
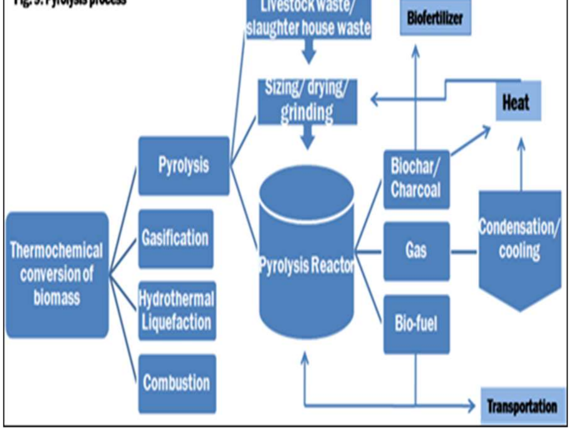


Fig. 8. Biodiesel production from livestock waste

thousands of years thus enriching soil with carbon and as a result increases production. Pyrolysis besides producing biochar also produces liquid (bio-oil) and gaseous products (Fig. 9). Pyrolysis of slaughterhouse wastes could also help in recovering phosphorus especially from bone char that can be used to produce phosphorus rich fertilizers hence leading to a sustainable phosphorus cycle.

Fig. 9. Pyrolysis process



Hydrothermal carbonization (HTC): A thermo-chemical treatment process where waste biomass is heated under low-temperature with pressurized water to produce a value added carbon-rich hydrochar material besides gaseous and water soluble products through hydrolysis, dehydration and decarboxylation processes. This method of converting waste biomass into a valuable solid hydrochar has an advantage over pyrolysis of using wet waste without pre-drying it. The carbon-rich hydro- char solid materials have high heating value, thermal stability, and the hydrophobic structure that makes their use in applications like solid fuels, adsorbents to remove pollutants (Kim *et al.*, 2018).

HTC further promotes nutrient recovery as both the hydrochar and the processed water contain essential nutrients like nitrogen, phosphorus and potassium that are very much important for plant growth. *Extraction of keratin/protein:* Keratin is a natural structural fibrous protein also referred as scleroprotein found in vertebrates making up scales, hair, nails, feathers, wool, horns, claws and hooves and outer layer of skin in mammals, birds and reptiles. Keratin hydrolysate has been used in shampoos for strengthening the hair and keeping its good appearance. It has several applications in pharmaceutical, biomedical, food, and cosmetic industries. Since, the feathers are rich sources of keratin, poultry feather waste has great utilization potential in various applications (Li, 2019).

Production of fibre board: Fibreboard is an engineered wool product that is made of wood fibres. Research is being carried out for the fabrication of fibreboards from mixed waste poultry feathers and wood residues (Safari *et al.*, 2020). Fibreboard samples were prepared by mixing feathers with wood shavings (coarse structure) or mixed wood residues (finer and denser structure) in different proportions. Similarly, Bessa *et al.* (2017) studied the use of chicken feather fibres in the strengthening of polymeric matrices and reported the suitability in terms of good acoustic and thermal insulation. Therefore, the technologies or innovations in utilizing the solid organic animal wastes in production of fibreboards, mattresses or other insulating materials will be invited in coming years as the food of animal origin will be in great demand hence more waste production.

Fabrication of bioplastic sheets: Synthetic plastic use is now restricted due to its non-degradability and environmental issues, hence, are gradually being replaced by bioplastic materials. Bioplastic sheets are biodegradable in which degradation results from action of naturally occurring microorganisms. Slaughterhouse/poultry wastes are one of the renewable sources of protein that can be used for the fabrication of bioplastic films. Lukubira and Ogale (2013) evaluated the effect of chemical modification of plasticized meat and bone meal (with a composition of 4–7% moisture, 50% protein, 8–12% fat, and 35% ash) by the calcium hydroxide on bioplastic sheets for geo-structural uses. However, the bioplastic sheets thus produced were weak as compared to synthetic polymers in tensile strength. Extensive research is required to utilize the organic animal solid waste in biodegradable plastic with good tensile strength to replace synthetic plastic.

Innovative use of smart phone technology

Phenomics and its recording are not at its best in India. This is one of the major factors that limit the application of scientific breeding and management in Indian agriculture.

Several Android software applications and kiosks have been developed in India aiming at efficient knowledge dissemination to farmers. This technology post Covid has been used efficiently in telemedicine and information dissemination. Many Apps have been developed to benefit farmers providing them weather information, advisories for management practices, disease prevention, disease outbreaks, vaccination and market trends.The increasing human population demands more food production. Urbanization and improved incomes have shifted dietary preferences more towards food of animal origin. It will be essential to concentrate in livestock production systems to fulfil the demands of people and ensure their food & nutritional security. Livestock farming has been caught into a mess of greater contributor of climate change, hence livestock farming demands practices that are aimed to decrease carbon foot prints in its production system. Therefore, use of emerging technologies/ innovations like sensor based automation, robotics, AI-ML, IoT, ANN, smart phone in farm practices and similarly, technologies to minimize the waste and convert it to wealth through use of innovative techniques are inevitable.

Conclusion

It is clear beyond doubt that conventional livestock farming is not going to sustain safe, clean, sufficient, affordable and accessible food security. Ever increasing, health-conscious human population, shrinking agriculture land, soil degradation, environmental pollution and climate change are big challenges in providing sufficient and safe food and to alleviate the malnutrition. The introduction of mechanization and biotechnological tools in agriculture food production systems has increased food production tremendously and supported the everyday increasing human population. However, in this race the natural resources were not judicially used and thus resulted into depletion of resources and degradation of soil. The use of modern tools and techniques in sustainable food production is inevitable to ensure food & nutritional security. New evolving technologies like internet of things, digitization, sensor technology, artificial intelligence, machine learning, robotics and data analysis have emerged as game-changer technologies that are affecting every sphere of life and have resulted into a significant shift in the ways the things were done. Livestock sector cannot afford to continue with all those traditional systems of farming, when the demands for food of animal origin are increasing continuously. Therefore, use of emerging technologies in the livestock farming and food production systems is obvious and inevitable to have sustainable food and nutritional security of increasing population and respecting the use of natural resources

Conflict of interest

The authors declare that they have no conflict of interest.

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