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Discussion Paper: Pests, Pandemics, Preparedness and Bio-Security

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India is projected to contribute 1.5 billion of the estimated population of 8.6 billion worldwide by 2030 (United Nations, 2017). India though a growing global power with consistent high economic and technological growth yet the share of agriculture in the gross domestic product is declining. Reduced input-use efficiency of the factors of production, soil organic carbon and fertility, water table, nutrition and livelihood security, food safety coupled with vagaries of climate change, and increased pests and pandemics and man-animal conflict due to overlapping food niche characterize Indian agriculture at present (ICAR Vision 2030, 2020). Agriculture offers livelihood to about 58 per cent of India's 1.38 billion population. The production of food grain and horticultural crops are 296 and 320 million metric tonnes (MMT), respectively, from 142 million ha leading to apparent self-sufficiency. Furthermore, ~ US$ 29 billion was the share of export during 2020. India has the largest livestock population of 536 million (31per cent of world) with milk production of 198 MT at a growth rate of 10 per cent year on year basis (IBEF, 2020). Poultry at 852 million (DAHD, 2020) together with livestock and fisheries contributes to protein nutrition. Fisheries and allied sectors provide livelihood to more than 14.5 million and the marine resources of India comprise an exclusive economic zone of two million sq.km, a continental shelf area of 30,000 sq.km and a coastline of 8,118 km with annual marine fish landings of 3.50 million tonnes (CMFRI, 2020). Agriculture and allied sectors remain fulcrum in determining the country's social and economic status in terms of food, nutritional and environmental security. Paradoxically, ~80 per cent of land mass is highly vulnerable to drought, floods and cyclones, the frequency and severity of the latter increasing year after year under the

influence of climate change. Malnutrition in children below the age of five (Anonymous, 2020a) and poverty amongst 6.7 per cent (Anonymous, 2020b) of Indian population are running parallel to shrinking land for crop cultivation, burgeoning population, climate change, global competition, environmental consciousness and changing lifestyles with food safety expectations. Demand projections for food grains is 345 million tonnes by 2030 and high-value commodities of horticulture, dairy, livestock and fish is increasing faster than food grains by more than 100 per cent. One of the serious impediments in enhancing productivity with sustainability to achieve the millennium goals is the and pandemics, which cut at the edifice of production and productivity across sectors of agriculture, horticulture, livestock and fisheries, threaten biodiversity, food safety and ecosystem services.

Pests are both native and transboundary in nature affecting human health, agriculture-cum-allied sectors. World witnessed many trans-boundary pest outbreaks, some regional and others pandemic in nature. Their outbreak or epidemics or pandemics lead to famine as in locust plague and mass migration as in the case of late blight of potato leading to economic, environmental and social chaos. This is very true when zoonotic impact human health on a global scale. India, being a predominantly tropical/subtropical country, and with little elasticity between demand and production, even a small upheaval can lead to strong social and political turmoil as seen with disease impacting onions, tomato and potato. Very often, the impact of pests and pandemics on the natural biodiversity and ecosystem services is direct. The indirect costs associated with ecological imbalance, food safety, migration, and health go unnoticed and unaccounted. Increased travel and international trading of agricultural commodities amidst fluctuating environmental factors and changing sociocultural milieu has continuously contributed to new and emerging pests in India in the last 50 years including the recent pandemics of coronavirus disease 2019 (COVID-19). India by 2030 needs a hectare of land to feed five persons against two at present. Similarly, per capita nutritional requirement will go up from the present 2 495 to 3 000 kilo calories/person requiring 5.5 million tonnes of food grain production per annum. Continued rural migration to urban areas, increase in wealth and shift towards diets rich in meat and dairy will alter the demography and food habits. Global trade, travel and climate change impact all systems of the one earth but the intentional and unnoticeable effects of various factors of pest dynamics require a wholesome biosecurity that allows careful capture of significant temporal and spatial trends of biodiversity and ecosystem services with the objective of mitigating potential threats before they assume pandemic proportion. Thus, in an era of aspirations for achieving food and nutritional security with food and environmental safety amidst climate change, it is imperative to address the status of pests, pandemics and the preparedness to tackle them from a scientific biosecurity framework. The current thematic paper examines the key problems of pests, and possible pandemics amongst various components (human/plants/animals/birds/fish) in the Indian context while examining the possible steps to be undertaken in the coming decade towards mitigation keeping sustainability development goals in focus.

Pests and pandemics: Humans

India has a vast unfinished task in preventing, controlling or eliminating major communicable diseases of humans and in bringing down the risk of deaths in maternal and peri-natal condition (Srinivasan, 2020). Given the seasonal pattern of epidemics each year, diseases like dengue, malaria, seasonal influenza, leptospirosis, chikungunya, enteric fever etc., present a diagnostic dilemma and also co-exist with COVID-19 pandemics (GoI, 2020). Endemic diseases arising from infections or lack of nutrition continue to account for almost two- thirds of mortality and morbidity. Of the contagious diseases affecting humans, more than 65 per cent are of zoonotic or animal to human origin (Anonymous, 2020c). COVID-19 is a part of worldwide pandemic caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and fortunately country's fatality rate was among the lowest in world at 2.41 per cent. As on 5 December 2020, in India the total number of COVID-19 cases is 0.956 million out of global tally of 1.5 million with total deaths of 0.14 million so far (Anonymous, 2020d). Dengue is the fast-spreading mosquito-borne viral disease transmitted by day-biting *Aedes aegypti* mosquito and the number of dengue cases and deaths in 2019 were 157 315 and 166, respectively. With no specific treatment for dengue, proper case management can reduce fatality rates less than 1 per cent *A. aegypti* and *A. albopictus* also spread zika and chikungunya. The number of chikungunya cases in 2019 was 12 205. Chikungunya although is rarely fatal with full recovery of most patients, the chronic joint pain, and associated problems last for several weeks or months. Malaria, an acute disease caused by plasmodium parasites, is transmitted through female *Anopheles* mosquitoes (NVBDCP, 2019). India represents 3 per cent of the global malaria (228 million) cases with 95 per cent population residing in endemic areas. Viral encephalitis transmitted by *Culex* mosquitoes is another zoonotic disease especially in Bihar. Kyasanur forest disease, also called monkey fever, is a tick-borne zoonotic haemorrhagic virus that causes viral epizootics with high fatality in primates. This endemic disease of Karnataka is also observed in Tamil Nadu, Goa, Maharashtra and Kerala along the Western Ghats (Mourya and Yadav 2016) with 400-500 human cases reported per year (CDC, 2020). In recent years, humans themselves are exposed to many diseases because of working in open fields. It was substantiated that deforestation and extensive rubber cultivation offers an ideal breeding ground for *Ades aegypti*, the vector of dengue and chikungunya. The urban migrant community of workers also become carriers of these diseases and spread to rural dwellings. Extensive travel has facilitated resurgence of pests such as bed bugs across the world. During times of COVID-19 of 2020, it was observed that the incidence of the dengue fever in many parts of India was substantially lower on account of restricted travel both by road and air due to Government imposed quarantines and lock downs. Explosion of many other communicable diseases is expected in future as implementation of current quarantine measures will not be permanent or for over a long period of time.

Pests and Pandemics: Crops

Potential productivity of agricultural and horticultural crops is challenged by insect pests, diseases, weeds, nematodes and some vertebrates. Their impacts on farmers, consumers and all

organisms down the food web are significant and often devastating. During each cultivation cycle of agricultural and horticultural crops, production, and productivity losses of ~15.7 per cent occur in India owing to pests (Dhaliwal et al., 2015) accounting to ~US$ 36 billion. Of the 173 invasive alien species documented, 54, 25 and 22 represent terrestrial plant species, pathogens, and insects, respectively till 2018 (Sandilyan, 2016).

Transboundary Plant Pests

Transboundary pests are a serious threat to food security and environment, a condition exacerbated in recent decades by the globalized movement of people and commodities. India witnessed an upsurge of desert locust in 2020 with their swarms attaining epidemic proportions during COVID-19 pandemic. Rajasthan was on high alert with swarms entering Madhya Pradesh, Uttar Pradesh, Punjab, Haryana Gujarat, and Telangana between May and June. As on July first week, FAO had placed high alert with the possibility of more swarms of locusts likely to migrate from Somalia to along India-Pakistan border (FAO, 2020 a, b) and it remains to be seen whether a locust plague is in the offing. Cassava mealybug (CMB) is the latest invasive insect in 2020 first observed in Thrissur, Kerala (Joshi et al., 2020)[19] and has spread to Tamil Nadu causing 9 to 46 per cent infestation. Prevention of spread to unaffected areas and action for eradication (ICAR-NBAIR, 2020)[20] and importation of CMB-specific parasitoid, *Anagyrus lopezi* is currently underway. The fall armyworm (FAW) invaded India on maize during May 2018, and spread across all maize growing states. Recently it was also reported from Bangladesh. India recommended eight insecticides with conservation and augmentative biocontrol-cum-cultural control interventions given prime importance (AFFRC, 2019)[21]. Rugose spiralling whitefly (RSW), first noticed on coconut from Tamil Nadu and Kerala in 2016, later spread to Andhra Pradesh, Karnataka, Goa and Assam, through infested seedlings and transportation of plant materials (CPCRI, 2019). Banana, mango, sapota, guava, cashew, maize, ramphal, oil palm, Indian almond, water apple, jack fruit and many ornamental plants are host crops of RSW (NBAIR, 2020). Natural build of the parasitoid, *Encarsia* in RSW endemic areas and enhancing its niche survival are given focus at present. South American tomato moth (SATM), an invasive insect on tomato both under greenhouse and field conditions, was reported in 2014 (Sridhar et al., 2014) with its spread to several states, has established as a regular pest. While natural incidence of *Metarhizium anisopliae* on larval SATM was up to 35 per cent, resistance breeding through screening of wild and cultivated tomato genotypes is underway as a long-term management strategy. Papaya mealybug (PMB) caused significant damage to agricultural and horticultural crops since its documentation in 2007 at Coimbatore, Tamil Nadu. Mulberry crop over 1,500 ha in Tamil Nadu too got destroyed (Shekhar et al., 2011). However, classical biological control using *Acerophagus papayae* from Puerto Rico is a success story that reduced incidence of PMB from 49 to 3 per cent. Cotton mealybug (CMB) first recorded in Gujarat in 2005 caused yield loss of 30-40 per cent in Punjab amounting INR 1 590 million during 2007 (Dhaw an et al., 2007) and 40-50 per cent in Gujarat. Infestation of CMB was reported amongst 71, 141, 124 and 194 species of plants belonging to 27, 45, 43 and 50 families, respectively,

across cotton growing zones in India (Vennila et al., 2011) and the parasitoid, *Aenasius bambawalei* offered fortuitous biological control (Gautam et al., 2009). Invasive eucalyptus gall wasp (EGW) of 2001 (Anonymous (2007), spread across south (Jacob et al., 2007), central (Kumar et al., 2007), and northern states threatened the productivity of paper and pulp industry in 2007, however, is being kept under check presently by the native parasitoids (Ramanagouda et al., 2011). Other established invasive plant pests in India include silver leaf whitefly (Ananthakrishnan, 2009), coconut eriopyhid mite (Sathiamma et al., 1998), spiralling whitefly (Mani, 2010) and coffee berry borer (Singh and Ballal, 1991) that are managed on need basis. Occurrence of *Fusarium* wilt (race 1) infecting Cavendish in 2010 (Thangavelu et al., 2011) and tropical race 4 (TR4) reported from Uttar Pradesh in 2017 was also recorded from Bihar, Madhya Pradesh, Gujarat, and Maharashtra. Productivity of banana, especially Cavendish varieties is highly reduced by TR4 in several parts of the country (FAO, 2019) and the poor man's source of nutrition was at stake. Infected areas in Bihar and Uttar Pradesh saw a remarkable control of TR4 on account of microbial consortium developed by Indian Council of Agricultural Research. Citrus greening disease is destructive in major citrus belts of Maharashtra, Punjab, Southern and North-East India with its transmission through grafts and psyllid vector (Das, 2008) necessitating supply of disease-free citrus seedlings to reduce its incidence and damage.

Emerging pest problems: Insects and diseases

Pest problems from the categories of insects, diseases, nematodes, and weeds amongst economically important crops of agriculture and horticulture including protected cultivation emerge or change due to alteration in climate, crop production system and practices. Outbreaks of plant hoppers (Chander and Patel, 2010, Prakash et al., 2014, Anonymous, 2018) and swarming caterpillar (Anonymous (2009, Tanwar et al., 2010) on rice are noticed every now and then owing to congenial weather exacerbated by excessive nitrogenous fertilizers, closer spacing and indiscriminate insecticide use. Neck blast in Karnataka during periods of unseasonal rainfall (Chethana et al., 2016) and bakanae (Bashyal et al., 2014, Gupta et al., 2015) occurrence across basmati growing tracts are diseases of rice creating havoc. Increasing incidence of aphids in wheat, barley and oats (Sharma and Saharan, 2011), and yellow/stripe rust of wheat in severe form at certain pockets of north Indian states (Sharma, 2014) make the emerging scenario. At a time when per capita consumption of protein is declining with a greater number of mouths to feed, the production of pulse crops is threatened by biotic risks such as gram pod borer, spotted pod borer, pod sucking bugs and pod fly in addition to the major fungal and wilt diseases. A recent phenomenon is the delayed withdrawal of South West monsoon and excess precipitation leading to many fungal diseases across crops including pulses in Karnataka and Maharashtra. Outbreaks of defoliators on soybean in Maharashtra in 2008 (Lokare et al., 2014), stem rot on groundnut at north West Bengal (Baskey et al., 2020) and sunflower necrosis (Sardaru et al., 2013) add to perennial shortage of edible oils in India, wherein, the imports exceed domestic production. Increased incidence of bollworms/borers, resistance to *Bt* in pink bollworm and sap

feeding insects such as whitefly in Punjab in 2015 take a toll on production and productivity of cotton. Changing scenarios of insects during and post *Bt* era are a continuum with current plant protection revolving around pink bollworm and sap feeders (ICAR-NCIPM, 2019). White grubs (Anonymous, 2017) and disease *pokkah boeng* (Viswanathan, 2020) gained importance in recent years.

Sucking insects (hoppers, mites, thrips, and whitefly) pose significant problems to horticultural production. Many species besides being direct pests, are effective vectors of plant pathogens such as viruses and phytoplasma. While fruit fly complex is a major problem in many horticultural crops, leaf weevil devastating mango and litchi in Punjab (Sharma et al., 2015), mango shoot gall psylla at Uttarakhand (Kadam et al., 2017), sapota seed borer in Maharashtra (Patel, 2001), and litchi stink bug outbreak in Jharkhand (Jaipal et al., 2013) are hindrances to fruit cultivation. Bacterial blight of pomegranate epidemic in Karnataka, Andhra Pradesh and Maharashtra (Mondal and Sharma, 2009) and sudden mango decline in Andhra Pradesh and anthracnose on fruits cause widespread damage. Incidence of chilli gall midge (Nagaraju, 2000) and *Solenopsis* mealy bug attacking vegetables of Malvaceae, Solanaceae, Leguminosae and Cucurbitaceae are the emerging problems. Whitefly as a sucking pest and vector cause extensive economic damage in chilli, tomato and okra (Halder et al., 2013). Hadda beetle on cowpea and bitter gourd (Singh et al., 2014), plume moth in bottle gourd (Rai et al., 2014) and diamondback moth in crucifers (Ahmed et al., 2009) also cause serious menace. Potato late blight, an annual threat of North India (Chowdappa et al., 2011), has been causing epidemics in southern states of India on tomato and potato since 2008 (Chowdappa et al., 2013) possibly due 13_A2 clonal lineage introduced from Europe (Chowdappa et al., 2015). Giant African snail is detrimental to colocasia, elephant foot yam, cucumber, cow pea, field bean, pea, ladies' finger, and tomato with its sporadic outbreaks amongst crops of bitter gourd, beans, bottle gourd, chilli, tomato and cauliflower (Puri and Mote, 2004). Diseases caused by tospoviruses (Prabhakar et al., 2017) vectored by thrips have emerged as a limiting factor for the sustainable production of tomato and watermelon. Aphid transmitted papaya ring spot virus is of major significance that can impact availability of vitamin A to the common man. *Stemphylium* blight and iris yellow spot virus associated with onions and anthracnose on many horticultural crops are emerging as serious threats amongst diseases. Occurrence of insect and diseases inside polyhouses exceed open field cultivation because of favourable moisture and humidity (Singh et al., 2017) and absence of environmental resistance. The uninterrupted cultivation under greenhouses contributed towards high incidences of soil-borne diseases (Sharma, 2012) and especially root knot nematodes. Severity of powdery mildew, bacterial wilt and root rots was more alarming with *tospo* and leaf curl viral diseases dominance in protected cultivation (Somasekhar et al., 2012).

Emerging pest problems: Nematodes and weeds

Nematode problem is gaining momentum across all cropping systems of Indian agriculture. Plant-parasitic nematodes cause 21.3 per cent crop losses across 19 horticultural and 11 field

crops (Kumar et al., 2020). Root knot, reniform, lesion, foliar, burrowing and bulb-cum-stem nematodes are the most destructive and difficult to control pests that certifications have become essential nowadays for protected cultivation in glass and polyhouses. Both ecto- and endo-parasitic nematodes inflicting serious damage are a cause of concern in forest. A potential risk of introduction of pine wilt nematode in the Himalayan region of Indian territory exists through the import of coniferous wood and wood products especially from China through Nepal, Bhutan and Myanmar (Khan, 2020). Declining organic matter and pH directed micro-irrigation and fertigation have accentuated the problem both in the open and protected conditions. Weeds also cause reduction in yields of various crops and are more harmful than insects and diseases with potential crop yield losses ranging between 15 and 76 per cent (Gharde et al., 2018). Herbicide resistance in weeds, changing climate, direct-seeded rice and zero cultivation led weed species, plant parasitic *Orobanche* in mustard and alien weeds viz., *Parthenium*, *Lantana*, *Ageratum*, *Chromolaena* and *Mikania* (Rao, 2018) have become aggressive despite wider use of chemical and bioherbicides for weed control (Kaur et al., 2014).

Pests and pandemics: Livestock

Vast agroclimatic, geographical regions and cultural differences have led to differential husbandry practices as well as diseases occurrence amongst livestock. In recent years, emerging and re-emerging diseases of livestock, poultry and piggery have tremendously increased vis-a-vis higher demand and supply for meat, milk, eggs and fish. Fresh and processed products are witnessing increased trade and likelihood of carriers of contaminants. Breach of biosecurity in intensified livestock production and management systems is often the reason for spread of zoonotic and other animal diseases with considerable impact on public health. The societal conundrum that exists in the country prohibits the drastic measure of slaughtering and disposal of the infested and in-contact animals and hence the rate and speed of disease spread are faster even if identified on time; besides wet markets, across the country, are very conducive for zoonotic diseases. Foot and mouth disease (FMD) is a continuing epidemic decreasing the productivity of cattle, meat, wool etc., due to unrestricted movement of animals across Indian states and incomplete vaccination. In areas of control of FMD, there is built-up of herd immunity and substantial fall (Subramaniam et al., 2013). Outbreak of *Peste-des-petits ruminants* affecting goats and sheep in Tripura is transboundary disease (Begum et al., 2016) and about 99 per cent nucleotide identities existed with Bangladeshi viral strains (Muthuchelvan et al., 2014). Several PPR outbreaks were encountered in India with high morbidity (50-90 per cent) and mortality (50-85 per cent; Muthuchelvan et al., 2015). Bluetongue transmitted by *Culicoides* spp. was severe in Karnataka, Andhra Pradesh and Tamil Nadu (Hemadri and Hiremath, 2011) and impacted the farmers in the recent past. Lumpy skin disease (Anonymous, 2020e), a capripox infectious viral disease, transmitted by mosquitoes and flies is fast spreading among cattle and bovines in districts of Maharashtra and Assam. Sheep poxvirus and goat poxvirus cause economic loss to small ruminant husbandry with mortality of young animals exceeding 50 per cent in almost all states (Bhanuprakash et al., 2011). Bovine herpesvirus-1, higher in crossbred

and exotic breeds, cause economic losses through reduction of milk yield and impact on national and international trade of germplasm and livestock. Bovine viral diarrhoea in cattle (Sood et al., 2007), sheep and goats (Mishra et al., 2009) and buffaloes (Mishra et al., 2008) are also important. Picobirnaviruses are emerging threat to mammalian and avian species associated with enteric and respiratory infections. Bacterial diseases viz., haemorrhagic septicaemia, blackquarter, anthrax, brucellosis, leptospirosis, listeriosis, tuberculosis, bovine tuberculosis and paratuberculosis are infectious amongst livestock with some of them having zoonotic significance. Anthrax is one of the top five zoonotic diseases in India. Listeriosis is also fatal to ruminants (sheep, goat, cattle, buffalo, camel), non-ruminants (horse, pig, canine, rodent, wild animals, birds) and humans (Dhama et al., 2013, 2015). Bovine tuberculosis is a chronic bacterial zoonotic disease, which easily spreads to humans through inhalation of aerosols or ingestion of unpasteurized infected milk (Prasad et al., 2005). Parasitic diseases viz., fascioliasis in sheep, trypanosomiasis in wild animals, dogs, horses, camels, donkeys, cattle and buffaloes, bovine tropical theileriosis in indigenous cattle and crossbreeds and babesiosis in bovines are regular pests of ruminants (Saminathan et al., 2016). Recent incidence of tick-borne disease causing congo-haemorrhagic fever associated with sheep has made inroads into Rajasthan and is an emerging zoonotic disease (Tripathi et al., 2020). The slaughterhouse wastes thrown outside also become agents for further spread of vector-borne disease of animals closely associated with wet market. Although rinderpest of cattle in the past has been eradicated, the same cannot be said of FMD and anthrax diseases.

In pigs, incidence of brucellosis, swine erysipelas, greasy pig disease, *Streptococcus suis* infection and methicillin resistant *Staphylococcus aureus* infections are common and widespread. Injudicious use of antimicrobials in pig rearing has resulted in emergence of multiple drug-resistant bacteria with significant public health implications. Antimicrobial resistant bacteria are transmitted to humans through direct contact and through the environment, pork and pork products (Rajkhowa et al., 2014). Viral diseases among pigs are classical swine fever, rotavirus infection, FMD and porcine reproductive and respiratory syndrome. India reported first case of African swine fever and its outbreaks in Assam and Arunachal Pradesh both in domestic pigs and wild boar during 2020. Porcine circovirus-2 infection is an emerging disease and its tracking of the epidemiological pattern in north east hilly regions of India (28 per cent of pig population) gives an alarm for alertness (Rajesh et al., 2020). Diseases of poultry that have produced historical panzootic along with zoonoses are avian influenza and Newcastle (Ranikhet) disease. Furthermore, viral diseases viz., fowl pox and avian leukosis, the bacterial diseases like tuberculosis, fowl cholera and *Escherichia coli* infections cause outbreaks in poultry farms. Other fatal infections are due to tick fever, infectious coryza, protozoans causing coccidiosis, internal (round and tape worms) and external (lice, ticks, mites, and fleas) parasites are debilitating pestilence to birds and workers (Singh, 2020). Avian malaria can also be threatening to the poultry and needs to be kept under vigil. Farm families are often exposed to

the bovine encephalitis, swine flu and many other diseases of piggery in addition to virus influenza of poultry.

Pests and pandemics: Fisheries

Primary constraint to sustainable aquaculture is the occurrence of diseases affecting product trade and socioeconomic status of fishers. Growth of shrimp aquaculture in India during last two decades has significantly increased the diseases (Pantoja et al., 2008). The loss due to disease outbreaks in shrimp farms located in nine coastal districts was estimated to be INR 10 000 million (Binesh and Jithendran, 2013). Disease occurrence is variable in ponds, open-water and cage culture. Mostly, the protozoan ciliates, monogenetic trematodes and crustacean ectoparasites are reported. The *Ichthyopthirius,* cause white spot or Ich in freshwater fishes. Bacterial diseases of septicaemia, edwadsiellosis, flexibacteriosis, bacterial gill disease, mycobacteriosis and columnaris are often reported in semi-intensive or intensive pond culture systems (Das, 1999, Fegan et al.,1991). Saprolegniasis and epizootic ulcerative syndrome are important fungal diseases in fish culture (Durai et al., 2015). Many viral infections viz., white tail/white muscle, monodon baculovirus, yellow head disease, white spot disease, taura syndrome virus, infectious hypodermal and hematopoietic necrosis virus, hepatopancreatic parvovirus, infectious myonecrosis virus, acute hepatopancreatic necrosis/early mortality syndrome and hepatopancreatic microsporidiosis are of concern to Indian aquaculture (Mishra et al., 2017). Cyprinid herpesvius-2, koi ranavirus, carp edema virus, megalocytiviris and goldfish hematopoietic necrosis herpes virus are the diseases of ornamental fish culture (Glazebrook et al., 1990). Outbreaks of Tilapia lake virus was reported in West Bengal and Kerala (Behera et al., 2014). Intensive shrimp farming with imported *Penaeus vannamei* (Rajendran et al., 2016) brought in microsporidians, which is causing huge loss to Indian shrimp industry.

Pests and pandemics – Effects on food, nutrition, employment and environment

In India, with its higher population density and poverty, the requirement of food and nutrition is of paramount importance for development of children and adults including women. Number of persons in the age group of 50 and above would increase significantly in coming years with each one requiring different but calibrated approaches regarding energy and protein that are exceptionally high. Indian farming is becoming more complex due to competing factors of growing population, land competition, climate change, food, feed and nutritional expectations, labour availability, mechanisation, producer and consumer dilemmas, price policies, scarce capital, environmental consciousness in addition to societal pressure on basic health and safety expectations and all these factors would offset the balance of country's economy vis-a-vis nutritional or energy requirements to be achieved in a sustainable way. Any reduction in supply of pulses and edible oils would impact growth and development of population especially those belonging to economically weaker section of the society. Horticultural crops serve as the best alternatives to food crops economically and ecologically in providing nutritional security. Both fruits and vegetables are primary sources of minerals and proteins in addition to other

compounds such as antioxidants. The requirement of vitamin A, C, B_1, B_{12} and many others are absolutely met by the Indian mass to a larger extent through horticultural crops. Although, horticultural production seems to have increased whether it would keep pace with the increasing demands of rising population and the middle-class segment is a matter of concern. Social changes associated with rural youth shifting to urban areas for education and work vis-a-vis changing pattern of food preference have transformed the balance between demand and supply of type and quantity of food items not to mention of the variety of processed and semi-processed products in use.

Demand-driven growth in livestock production in rural and semi urban areas will enable millions of poor to escape the poverty trap besides contributing towards women empowerment. Share of poultry and other meat that serve as source of protein, vitamins and minerals is expected to grow from 12 to 24 per cent by 2030 on account of rapidly changing consumer behaviour. The poultry industry in India is constantly advancing due to the use of modern technology and switching from live bird to fresh chilled and frozen poultry product market. Poultry sector is to produce designer eggs. These are organic eggs rich in omega 3 fatty acids and with lower levels of saturated fats and cholesterol. Poultry industry with its growth rate of 12-15 per cent is not only providing a low cost source of dietary protein to the consumers but also employment opportunities. Unsafe disposal of poultry litter lead to multi-drug resistance properties in bacteria. Antibiotics such as tetracycline, doxycycline, and ciprofloxacin, critical to human health, are used for growth promotion in poultry. A more concerning issue is the use of colistin for growth promotion, prophylaxis, and therapeutic purposes in poultry. Rampant use of benzathine penicillin for animal use is obvious through six manufacturers as against just one for human use. Misuse of antibiotics and presence of *Salmonella* and cholesterol in poultry meat are the cases of unsafe food of human consumption. With increasing consumption of seafood globally, aquaculture has grown dramatically over the years and as per an estimated report infectious microbial diseases of fish cause loss of around US$ 6 billion each year. Changing forest expose the domestic livestock to a new range of pathogens and vectors that previously existed only in wildlife niches. Closer, overlapping contact between wildlife, animals and humans and organised livestock and poultry farming in close association with people promote spread of infectious diseases with potential to threaten health, economies and food security. Increased trade of raw commodities and processed foods carry the pathogens that act as food poisons affecting health of humans in addition to introducing new organism into countries and continents (Yadav et al., 2020). Whether it is food or nutritional security or human health they are all fundamentally interconnected and lack of nutritional food and its safety make the population susceptible to several diseases. Many of the pests and pandemics not only impact farmers directly at farm level but also through disruption of supply chain and position of agriculture at national level impacting food and nutrition of a wider population. Workers engaged in cattle, pig or poultry farming when impacted by zoonotic diseases migrate to their home districts or states that result in reduction of labour availability to farmers as it happened

with the pandemic of COVID-19. Mass movement or displacement of labour has not only left the employment in agricultural and non-agricultural sectors vacant but the movement itself served as a cause for secondary spread of pandemic.

Pests and pandemics - Effects on biodiversity

Most of the problems in agriculture from soil health, pestilence, zoonotic, pandemics and food safety can be traced to adverse impact of intensive, monocropping, seriously threatening natural as well as agrobiodiversity in soil, forests and aquatic systems. Pest infestation at a pandemic level reflects an invasive or loss of biodiversity. Population growth to 1.6 billion by 2050 seeks higher provisioning for energy and commodities aggravated by changing dietary habits and climate change. Demographic pressure would compel modification of natural landscapes and intensification of agriculture and allied sectors leading to biodiversity loss *per se*. Biodiversity loss leads to increased pests and pandemics. Epicentres shall sprout as humans, livestock and wildlife share large pools of microorganisms in proximity. Further, manifestations of new species or adaptation of existing species to new hosts would result in changing structure and rate of emerging infectious diseases as in the case of COVID-19. Loss of species can increase encounter rates between pathogens and hosts when the lost species are not hosts for the pathogen. Expansion of agricultural areas through deforestation can lead to increased wildlife-human and livestock-wildlife contact with livestock-human transmission leading to a range of infectious disease outbreaks and emergence events, and modification of transmission mechanism. Expansion of agricultural areas through deforestation can lead to increased wildlife-human and livestock-wildlife contact with livestock-human transmission leading to a range of infectious disease outbreaks and emergence events, and modification of transmission mechanism. Besides agricultural encroachment, road construction, logging, dam building, irrigation, wetland modification, mining, the concentration or expansion of urban environments, coastal zone degradation, in other words and modification of natural landscapes cause a cascade of factors that exacerbate infectious disease emergence. Use of drugs such as antibiotics, vaccines and agrochemicals destroy the biodiversity and openly impact the ecosystem services with the expected management practices of pests during pandemics. Indiscriminate policies and practices over the last 60-70 years with scant respect for environment and biodiversity have caused India maximum harm. The nation must resolve to leave the current forests and natural landscapes to safeguard biodiversity and to avoid frequent and virulent pest outbreaks. One of the factors leading to emergence of epicentres of zoonotic is the wet meat market especially when wild animals are slaughtered as in the case of COVID-19. Serious thinking on this is needed to prevent future zoonotic and epidemics so as not to repeat the events of Spanish flu of 1920 and COVID-19 of 2020.

Pests, pandemics and biosecurity

Most of the zoonotic viruses have significant possibilities in bioterrorism and have potential to wipe out humans and animals. Advances in molecular biology such as gene editing can make profound changes in genetic manipulations of organisms, and implications of such technologies in occurrence of pandemic and its mitigation need serious thinking. Institution of appropriate and timely biosecurity measures is an important instrument for protection and improvement of animal health. Breach in biosecurity due to ignorance and lapses in adoption of timely biosecurity measures in management of livestock, poultry and fish are salient reasons for the high incidence emerging and transboundary infectious diseases. India's stance, like most of the nations across the globe, to the ongoing COVID-19 biosecurity crisis is largely responsive and reactive than being proactive from a biosecurity perspective, exposing low level preparedness towards pandemics (Athavale, 2020). In India, biosecurity has remained next to biosafety even after four decades of legislation. The proposed Agricultural Biosecurity Bill and the National Biotechnology Regulatory Authority aim to establish an integrated national biosecurity system covering plant, animal and marine issues. Under the Integrated disease surveillance programme, a network of public laboratories with biosafety practices and infrastructure was established although upgradations are needed to be continuous considering technological advancements. In India, about 30 bio-safety level (BSL) laboratories of the level of BSL-III or BSL-II+ are currently under operation with only two BSL-IV facilities. Prevention of transmission of pathogens across intra- and inter-country borders warrants devising of biosecurity measures at par with international standards. International guidelines are developed by WHO, FAO and OIE (OIE, 2020) in respect of human, plant and animal pests and pandemics. For handling the most dangerous transboundary pests more of BSL- III and BSL-IV laboratories in the country are required to ensure biosafety, biosecurity and biocontainment. Biosecurity needs to be observed from farm to national to regional and international levels in a bottom-up approach. Farm level biosecurity practices are available for crops, cattle, sheep, pig, poultry and fish production systems with best designs in terms of phyto/zoo sanitary measures such as quarantine, rodent and vector control, disinfection of animal sheds and premises, proper disposal of dung, urine, feed and fodder wastes and proper carcass disposal for effective management of infectious diseases although ground level adherence is still wanting. India needs to take a look into its biosecurity preparedness and plug all the big gaps to prevent being blindsided to dangerous biological agents- either man-made or natural. A number of biosecurity preparedness measures applicable for zoonotic and human diseases, have implications for plant quarantine which is lagging behind leading to a cascade of invasive pests affecting field and horticultural crops.

Impact of climate change on pests and pandemics

Climate change through global warming, depletion of ozone layer, raise in sea level or increase in vector-borne and communicable diseases, has the potential to affect the agricultural production and hence pressure on livestock industry. Effects of climate change on animal production include climatic influences on quantity and quality of feed and fodder resources such

as pastures, forages, grain and crop residues and the severity and distribution of livestock diseases and parasites. Global warming could increase water, shelter, and energy requirements of livestock for meeting projected milk demands. Increasing sea and river water temperature is likely to affect fish breeding, migration, and harvests. Population dynamics of insect/vectors and epidemiology of diseases are highly influenced by temperature and relative humidity. It is predicted that climate change induced aberrations favour invasive pests and diseases at the cost of natural regulation. Heavy damages due to the pod borer in pigeon pea and chickpea from early warming (3-5°C) in North India and outbreaks of gram and spotted pod borers in South India due to unseasonal (extended) rains during October-November were observed (NCIPM, 2017). Trend of sucking insects (leafhoppers thrips) and peanut bud necrosis incidence on groundnut was greater at hot semi-arid over arid zones with associated climatic variabilities quantified (Vennila et al., 2018, 2019). It has come to the fore that despite insect transmitted, or vector-borne viral diseases cannot be controlled through pesticides, they will increase under the climate change scenarios. One of the pests that explode with higher temperature are the red spider mites that infest a wide range of crops both in the open and under protected conditions. It is not an understatement that most of the new insecticides are acaricides. The increased incidence of pathogens be it bacteria, spirochetes, viruses, phytoplasma etc., can drastically impact the productivity, nutritional quality besides the availability of seeds and quality planting materials. Although demographic pressures will continue to increase on crop production in the coming decade, the solution lies in understanding ecological dimensions of pandemics both at microlevel as in case of soil health, nematode infestation and soil-borne pathogens influenced by reduced soil organic matter and pH etc., and macrolevel climate change induced by global warming, excess and intensive precipitation. Weather based early warning system serves as climate resilient tools and in place for desert locust (aided by FAO), potato and grapes pests and diseases in India. Simple protocols for field level implementation on assessment of pests and pandemics using technology driven proxy indicators are being piloted under Pradhan Mantri Fasal Bima Yojana initiative of Government of India integrating multiple stakeholders on a single platform (PMFBY, 2020). A probable 10 to 40 per cent loss in crop production, likely aggravation of heat stress in dairy animals reducing milk production to the tune of 1.6 million tons and increasing sea and river water temperature impacting fish breeding, migration and harvest are projected (Prabhakar, 2018). Shift in distribution of vector-borne disease of livestock such as blue tongue that has 27 serotypes across the globe is anticipated (Shyam et al., 2014). The poultry segment faces a number of interrelated stress from climate change such as higher temperatures affecting growth rates, egg production and health and disease management. Poultry farming in Karnataka by 2030 with an increasing temperature (0·8-3·3°C) is likely to result in increasing incidences of heat stress-related morbidity and antibiotic use, the latter causing immune system compromise leaving broiler chickens more susceptible to bacterial infections (Jennifer and Jayant, 2019). Perception of coastal fishermen of Kerala indicated that the prime impact of climate change would be a sea level rise and consequent changes in habitat, frequency of extreme events,

variability in the catch and revenue of fishery followed by economic and environmental aspects with social parameter scoring the least (Vass et al., 2009).

On the positive side, limited social and industrial economic activities during COVID-19 pandemic resulted in improved air quality by 30-60 per cent (Mahato et al., 2020) although it could only be temporary. India has a strong and unique programme of National Innovations in Indian Climate Resilient Agriculture across all sectors of agriculture viz., crops, horticulture, livestock, fisheries, natural resource management and extension for research and development on one platform for addressing the impact of climate change. Development and implementation of multi-location, multi sector mitigative and adaptative cum resilient strategies to combat challenges posed by climate change to Indian agriculture is the mission (Prabhakar, 2018).

Pests and pandemics: Preparedness and policy needs

COVID-19 changed the very edifice our living, business, commerce, health, travel, education, research, and politics exposing the vulnerability of humankind and environ despite advancements of information technology, molecular biology, data management and communication involving multilateral global organizations such as World Health Organization (WHO, 2020), Food and Agricultural Organization of the United Nations (FAO, 2020c) and *Office International des Epizooties* (OIE, 2020;World Organization for Animal Health). At times, the exotic pests get under reported either due to non-detection or fear of losing trade. Since the direct and indirect losses due to pests and pandemics are economically and socially immeasurable and all countries are equally vulnerable, there is an urgent need for trans-national collaboration and co-operation through a global initiative to monitor, sensitize, train, and manage. Lessons from COVID-19 emphasized the need for transparency and acceptance of pandemic so that countries can take calibrated timely advance decisions to mitigate the pandemic. Global public health is led by WHO and coordinates International Outbreak Alert and Response is designed to ensure "outbreaks of potential international importance are rapidly verified and information is quickly shared within the Network" with commitment that all network responses will proceed with full respect for ethical standards, human rights, national and local laws, cultural sensitivities and tradition (WHO, 2020). Thus, ensuring each nation’s security, financial, and other interests will be given full focus. The Organization for Economic Co-operation and Development (OECD, 2020) has a primary mission to promote policies that will improve the economic and social well-being of people around the world.

India’s response to COVID-19 pandemic was through adoption of a comprehensive and robust lockdown restrictions for containing the rapid spread (COVID-19, 2020) and building necessary healthcare infrastructure. Government's swift and stringent actions, emergency policymaking, emergency investment in health care, fiscal stimulus, data management, international collaboration are noteworthy. Investment in vaccine and drug research and development showed the tremendous capacity (Times of India, 2020, Anonymous, 2020f) to deal with the outbreak owing to its vast experience in eradicating smallpox and polio under the National vector-borne disease control programme directly under Ministry of Health and Family Welfare.

National vector-borne disease control program, revised National tuberculosis control program, integrated disease surveillance project and National acquired immune disease syndrome control organisation are the major schemes. A network of 311 sentinel surveillance hospitals and 14 apex referral laboratories with advanced facilities located in 35 states/union territories for diagnosis of dengue and chikungunya exists in the country. Tuberculosis control program use WHO recommended directly observed treatment strategy and reaches over a billion people in 632 reporting units. Disease surveillance strengthens disease monitoring for infectious diseases to detect and respond to outbreaks quickly. Implementation of programs for prevention and control of acquired immunodeficiency syndrome/human immunodeficiency virus in India is through 35 societies (Anonymous, 2020g). Vaccination is the main strategy for control and eradication of many diseases. Good management practices consisting of stringent biosecurity measures, strict sanitation and hygiene practices in the farm, isolation and quarantine of diseased animals, and trade restrictions are implemented for successful operation of control programmes. It is a matter of pride that India is one of the largest producers of vaccines for the world, and this investment in research, infrastructure and development is mitigating several pandemic diseases across the globe.

Plant-quarantine legislation in India aims to secure protection from the ingress of exotic pests during import and export under the aegis of Department of plant protection and quarantine and storage, the National plant protection organization for the International Plant Protection Convention (IPPC) of United Nations. As the sole international standards setting body for plant health, the IPPC works closely with FAO, national and regional plant health authorities, academia and private sector representatives to lower the risks of fall armyworm under the framework of 'FAO global action on FAW control' (FAO, 2020d) in which India is also partnering. Department of Biotechnology under the Ministry of Science and Technology takes care of biosafety issues in dealing with genetically modified organisms, and issues on the biological warfare are dealt by the Ministry of Home Affairs. Centre for Animal Disease Research and Diagnosis of Indian Veterinary Research Institute, Izatnagar, with its five regional disease diagnostic laboratories and state diagnostic laboratories are involved in quarantine, eradication and vaccination/management of and animal, fish, respectively, following standards of the OIE that are further promoted by WHO and FAO. Chaudhary Charan Singh National Institute of Animal Health, Baghpat, is the nodal institute to quality control and licensing of veterinary biologicals in India. Several animal health schemes have been initiated in the states and centre such as National project on rinderpest eradication, contagious bovine pleuropneumonia eradication, FMD control and additional schemes and programmes are implemented by the Department of Animal Husbandry and Dairying under the Ministry of Fisheries, Animal Husbandry and Dairying of Government of India (Anonymous, 2020h). National accreditation board for testing and calibration laboratories is the sole accreditation body in India that provides third party assessment of the technical competence of testing including medical and calibration laboratories, proficiency testing providers and reference material producers (NABL, 2020).

Under Indian set up, lack of timely convergence amongst agencies often resulted in delayed declaration of pest invasiveness making detection surveys poor with slow or no eradication measures. Similarly, critical areas such as upgradation of diagnostic laboratories, quarantine facilities, strengthening of risk analysis mechanism, research prioritization, development of database and adherence to standard operation procedures of WHO/FAO/OIE need effective implementation. There is need for a stronger national biosecurity policy with coordination, collaboration and convergence amongst organizations, institutions, department and ministries for work on invasive and emerging pests with focus on developing pest risk-analysis models and early-warning system. Addressing issues from an environment, biosecurity and ecosystem services perspective and in a bottom-up approach starting from village to the region to nation to globe would contribute to automatic reduction of the numerous problems associated with human, plant and veterinary health. Human resources with expertise and well-defined roles need to be deployed with networking to a national platform having centralized reporting on transboundary and emerging pests. Regional microbial repository with bioinformatics on infectious diseases with their geographic and temporal distributions, barcoded/molecular characterized diagnostic protocols, strains/serotypes/lineages/variant groups, vaccine escape/drug resistant mutants and epidemiology along with services of pest risk mapping require greater attention. Pest diagnostics happen through visual, microscopic, fluoroscopic and radiographic methods, electronic nose (e-nose) systems (Cui et al., 2018), DNA barcoding, and high-throughput molecular methods. Environmental DNA (eDNA) technology coupled with isothermal nucleic acid amplification tests (iNAATs) including loop-mediated isothermal amplification (LAMP; Ministry of Agriculture, Forestry and Fisheries of Japan, 2019), biosensors, hyperspectral techniques and artificial intelligence are gaining importance in recent times. Forging alliance with a well-founded global supportive surveillance with good database policies would be an investment for present and immediate future of India.

Management of pests and pandemics at farm level although has gone through many transitional and scientific approaches, the holistic health management through tactical integrations and adoption of good agricultural practices must be supported by sound legal framework. Genetic improvement through molecular assisted selection and introgressive breeding for increased yields, tolerance/resistance against pests in crop-animal-avian and fish (Anonymous, 2020i) systems and desired fortification of (proteins/vitamins/minerals etc.), nutrients and are continuing pillars of food and livelihood security. Implementation of electronic (e)-pest surveillance and digital dissemination of advisories (Vennila et al., 2016) across different states for crop/animal and fish sectors have led to adoption of scientific pest management by the farming community. The ongoing programmes viz., crop pest surveillance and advisory project (CROPSAP, Maharashtra), horticulture pest surveillance and advisory project (HortSAP, Maharashtra) and e-pest surveillance in vegetables (Haryana) are a few successful examples for digital surveillance and delivery of the pest management advisories to farmers with absence of pest outbreaks. Many mobile apps as information and expert systems along crops and theme areas of plant protection are currently available (Vennila, 2016). Information network system for

animal productivity and health, a desktop/android-based field application facilitates capturing of real-time data on breeding, nutrition and health at farmer's doorstep. Features of easy replicability, extensive area coverage, efficient use of resources and extreme robustness of e-based pest surveillance fulfils the policy adoption of integrated pest management and 'Digital India' together. Surveys and surveillance at all levels of production systems would aid in immedia3te reporting of an invasive pests or outbreaks and the simultaneously offer alertness to everyone concerned. Surveys and surveillance require dedicated deployment of tools and personnel, and it has always been an endeavour of public sector. However, manufacturers and dealers of agri-inputs (seeds/fertilisers/farm machinery/agrochemicals/veterinary biologicals) should contribute to centralised platform of national surveillance with traceability associated with input distribution. Increased investment in infrastructure development with participation of private sector with backward and forward integration would be a better policy perspective.

In plant health management, India has a total of 292 pesticides registered and per hectare consumption of pesticides in India is on rise (600 g/ha) after 2009-10 (DPPQ, 2020). Injudicious use of pesticides has led to problems of resistance (Sethi and Dilawari, 2008, Fand et al., 2019, Dhaliwal and Koul, 2010, 2010C, Thind et al., 2009), resurgence and residues. Not all crops have registered plant protection chemicals and farmers often use off-label products that have implications on food safety and export. Hence grouping of crops and commodities (554 numbers) in line with the codex classification and guidelines for label expansion and recognition with respect to maximum residue limits was a step forward by the government. Pesticide market, which is projected to reach INR 292.9 billion by 2023 is fraught with non-genuine products in markets (Croplife, 2015). Recent draft notification on ban of 27 pesticides comprising 8 fungicides, 12 insecticides and 7 herbicides across 134 formulations for 74 crops is subject to scrutiny. Therefore, the Pesticide Management Bill 2020 must emphasize on adopting systematic standard operating procedures with transparency with optimization of benefits between the industries and growers mediated by government. Mass production technologies ready for agribusiness in biocontrol (ICAR-NBAIR, 2019) are in place for predators and parasitoids against insect pests and microbial pathogens of crops including those for the recently invaded FAW in maize. Upscaling the production of parasitoids, predators and microbials for large scale field use supplemented with enabling policies for quicker registration, quality assurance, are necessary for enhancing resilience of agroecosystems.

Sustainability is the most important factor that is not taken too seriously, and desired changes need to be implemented in livestock farming. India became free of the cattle plague, caused by rinderpest virus infection of livestock that existed since early 1950, following efforts over half a century through launching and relaunching of National Project on Rinderpest Eradication. Mass and revaccinations of goat tissue virus vaccines (GTV-Edwards and Plowrite and Ferris strains) helped the country to be rinderpest-free since 1 November 2004 endorsed by OIE in 2005. However, collaboration with many other countries continues as one of the preparedness with emphasis on surveillance and to develop as many vaccines as possible and storage (Yadav et al.,

2020). Although science led development of finding vaccines for viral diseases happens, their affordability and availability to cover entire population are lacking. It is largely the organised livestock and poultry farms that get the vaccines administered with nomadic/stray cattle left out continue to harbour diseases. High use of antibiotics in livestock and poultry production is most often attributed to low compliance with regulation and poor antimicrobial stewardship Laxminarayan and Chaudhury, 2016) as the costs associated with antimicrobial resistance in human health are an externality to the farming industry. Established system of systematic surveillance, co-ordination among vaccine producers, minimum quality standards, quality assurance and quality control for veterinary biologicals, centralized veterinary drug regulation authority, cold chain maintenance during vaccine transportation, indiscriminate vaccination specially in poultry and canines and awareness on farm level good livestock production practices are lacking.

Since growth of culture fisheries has increased the vulnerability to aquatic diseases to transboundary nature is high. Hence, in the globalized environment, issues of sharing water basins, transboundary movement of migratory fish species and aquatic animals, trade and India's alignment to international standards need attention. Regionally, coordinated, and cooperative management of shared fishery resources between the centre and states is required for long-term sustainability. Aquaculture sustainability also depends on improvement of germplasm and their screening, promotion of usage of specific pathogen-free seed stocks, disease management, farming through international collaboration/cooperation traceability, standards, testing and certification of aquaculture produce along with requisite regulatory framework and infrastructure. Aquaculture zonation and spatial planning consisting of identification of appropriate location, zones and common practice options help in management of diseases, environmental issues, post-harvest and marketing, mitigation of risks etc. At present, crop-livestock integrated systems are recommended for areas having irrigation facilities or receiving about 1 000 mm rainfall where production of surplus crop residues and allocation of some land for fodder cultivation and use of feed supplements are possible. Farming Murrah buffaloes, crossbred cows and mixed farming consisting crop with an inclusion of 10-20 synthetic backyard poultry breeds boosted income of farmers. Crop-livestock-poultry-fishery integrated farming systems are mostly suitable for high rainfall areas, where paddy is cultivated both in monsoon and after. Cows and or buffaloes are maintained at backyard with crop residues and supplements. Fish is reared in farm ponds and poultry is maintained in cages over the pond with grain and bran supplementation. The droppings of poultry serve as feed for the fish in the pond. Policy for sustainable farming and animal rearing through incentivizing farmers to adopt safe and healthy rearing practices of healthy feed/diets for livestock/poultry/fish, medication free rearing, safe disposal and safe processing is essential. Industry at large should be sensitised how higher use of antibiotics hampers sales of both poultry and fishery products in turn hampering health and sustainability. It is a sad story if these antibiotics enter honey in the food web. Enhancing the fodder supply, integrated production systems, value addition, information and knowledge sharing through farm advisories, crop-cum-livestock insurance, conservation and promotion of selective,

trait-specific native breeds, contingent fodder-animal planning, mitigation of greenhouse gas emissions, scaling-up of proven resilient production systems to spread the adaptation options and innovations to a wider community with capacity building of small holders would certainly build resilience of rainfed production systems in India.

Prospects of One Health approach

Indian agriculture is best personified by the small and marginal farming of crops, cattle (cows, buffaloes, sheep and goat), poultry, fisheries and a complex of many other activities simultaneously taking place. COVID-19 experience demonstrated in addition to loss of millions of human lives the destructive power and ripple effect of a pandemic invisible virus across the spectrum of health, education, travel, politics, livelihood and economics. In a globalized interconnected world with large-scale movement of men and material across the length and breadth of one world, no country or region is excluded from transboundary pests or pandemic diseases. Hence a revised strong regional and international cooperation, taking hard lessons from COVID-19 pandemic is an urgent need. Changing climate, rapid transport, travel, zoonotic influenced by overlap of man-animal overlap, organized animal husbandry, poultry, and climate change act as precursor for onset of diseases. Preparedness to tackle zoonotic infections of the future under conditions of climate change and environmental degradation require a concrete approach in unison exploiting the concept of 'one health' as it recognizes interconnectedness of human - animal - environment. 'One Health' is a globally accepted model for research on diagnosis, epidemiology and control of existing and emerging zoonotic threats through collaborative efforts of multiple disciplines working at local, national, regional and global levels to achieve optimal health for all as defined by its task force. India through Kerala Veterinary and Animal Sciences university (Anonymous, 2020c) has launched 'One Health' research centre for developing a sustainable disease control system using health analytics and data management tools to address the emerging zoonotic threats and prevent emergence of new communicable diseases. Approach of 'One Health' towards preparedness is a forward-looking continuum and requires a long-term commitment for research to thwart the emergence of new communicable diseases. Medical, veterinary, paramedical sectors and bioscience (agriculture and life science) researchers need to scale up the approach across the country with meaningful international collaborations.

Way Forward

The experiencing of COVID-19 pandemic taught the humanity at large its vulnerability to life and living, direct and indirect impacts on nation's biosecurity and socio economy of. Despite all the interlinked challenges of security and safety of food, environment, health and biodiversity, India's focus is towards sustainably increasing agricultural productivity, farm incomes, food security and sectoral development by building resilience at multiple levels. The diversified Indian agroecosystems and sectors are replete with history of pests and pandemics. Research-cum-developmental organizational set up and industries dealing with health system of human, livestock, poultry and fish have all the paraphernalia needed for an effective preparedness and

management of pests and pandemics. But their operational success is fraught with shortcomings of lack of coordination and collaborations. Individual excellence should translate to collective management. Slighter adjustments and reorientation in functioning of stakeholders interlinked through a common hub under 'one health' wheel would uplift the standards of diagnostics, preparedness and pest management. Pre-import and post-entry quarantine require need based international cooperation and collaboration. Redressal for new and emerging pests need inter departmental coordination. National diagnostic laboratories equipped with tools and trained human resources, exclusive electronic pest surveillance system using standard protocols, and field workers functioning together by convergence of public and private organizations/institutions/departments/industries should be mandatory. Surveillance must be aided compulsorily by geo reference based mobile apps developed using protocols adhering to international phytosanitary standards for invasive pests and national sampling procedures for management emerging pests. An *e*-reporting system involving artificial intelligence for diagnosis and data analytics integrated at server level with edaphic and weather factors represented in a geo platform would help in geo spatial early warning and subsequent pest management preparedness. Updated scientific information system linked to real time pest scenario derived from e-surveillance would facilitate digital pest management advisories automated for dissemination to end users. Forging a self-reliant integrated one-health management system require partnership of public and private stakeholders for needful production and supply of demand driven human/veterinary vaccines and quality pest protection products for plant/animal/poultry/fish.

Vertical integration of agricultural education is the key to improve quality of human resource in the country and many more post graduate students must be encouraged to address zoonosis, with focus on epidemiology, ecology, biodiversity, molecular characterization with expertise in big data analytics. Empowering agri-graduates and diploma holders to take up contractual system of plant-animal-poultry-fish protection in identified areas such as field pest/epidemic monitoring, bioagent mass production, manufacture of sensor-based gadgets, co-ordination of input supply and delivery system of agrichemicals/vaccines at farm level would be prudent to generate employment and to serve as pathway for securing a better health for all. Developing an entrepreneurial capacity for mass production of macrobials (parasitoids and predators), microbials (growth promoters, antimicrobials/antagonists), plant-based products and mechanical traps at cottage level would aid in sustaining natural farming systems. Registration of biological control agents that is quick, scientific and with quality assurance will provide impetus to commercialize the technologies. Policy framework facilitating execution of proactive strategies of plant protection by governmental departments with hand holding of growers and input industries is essential. No other time is better than the present for use of digital tools and mass media to execute a unified 'one health' system. Enhancing production and income of farmers through reduction of yield losses caused by pests should be the motto of plant pest management towards fostering national food, and environmental security. Human public health services are

given priority over veterinary and plant health in India including the poor insurance schemes for agriculture and allied sectors. However, human and environmental health could be simultaneously improved by the same policy or management actions provided agriculture and animal husbandry expansion and intensification, and other modifications of natural landscapes are implemented in a way that minimizes biodiversity losses. Media should play a very big role in educating the do's and don'ts during pandemics and hence, media management must go hand in hand with strong scientific research outputs and information reaching public in a simplified way.

Political environment of India with its neighbours and the rest of the world shall contribute towards sustainable development through mitigation of pests and pandemics. 'We are healthy if our neighbour is healthy' should be the slogan. India has a framework of 'environment' governed under Ministry of Environment and Forest with Ministry of Agriculture and Farmer's Welfare that functions for agriculture, animal husbandry and related sectors. Since environment is beyond forest and wildlife, there needs to be a separate Ministry of Environment that could address issues such as climate change, depletion of corals, loss of biodiversity, water, air and ecosystem services holistically and the wider scale of land agriculture, forests, seas, oceans, and mountains put together. Environment is global and cannot be confined to forests. Indian agriculture and forestry are two sides of the same coin and both must be accounted together to tackle problems of shrinking forests, agriculture and allied sectors.

India should align closely with the global community on aspects of carbon emission or footprints and global warming pertaining to climate change both at regional and global level. The melting of ice especially in Himalayan regions and associated soil erosion down the plains need a preparedness. Accurate monitoring of natural disasters of cyclones, drought hailstorms and floods and their forecasts strengthen the preparedness at local and macro level. Health management approach at local level for different sectors must be based on each of agroecological region of different agroclimatic zones of the country with revisits made once in five years for suitable calibrated changes. Sustainable production system begins with natural resource management. Soil health and its enrichment come with enhancement of soil carbon and biodiversity through vegetation and other means. Rivers and water reservoirs are lifeline of entire population and the water consumed and utilized for various purposes need safety guards for which stringent policy decision for each river basin must be promulgated. Considering that agriculture and allied sectors are state subject in India, investment into improvement of organizational set up such as setting up of plant/animal/fish health clinics equipped with infrastructure for training and advisory and linking the supply chain of agrochemical/antimicrobial/vaccine marketing through such clinics are needed. Nevertheless, a governmental or contractual system of field pest management using standard operating procedures is a plausible strategy. Innovative institutional models, pro-agricultural policies and regulatory mechanisms would accelerate innovations, ensure food security, enhance livelihood opportunities of smallholders, and conserve natural resources.

Conclusion

Invasion by new pests and pandemics may continue but science-led global cooperation and collaboration should be able to mitigate their impact more effectively. Precise and quick diagnostics and immunisations with quality vaccines are a must considering the loss of lives and health of human, crop, livestock and fish due to viral pandemics. Improvements and utilisation of resistant genetic stocks of crops/animals and fish with focus on increasing immunity in humans as producers and consumers, understanding the epidemiology and environmental interactions of pests and pandemics through advanced analytics, exploitation of biotechnological tools and food processing techniques of therapeutics with inbuilt biosecurity-cum-biosafety supplemented with quarantine legislations associated with trade formulated by stakeholders and policy makers together need positive transformations towards sustaining food and health systems. Like delayed justice, delayed mitigation of pandemic is a denied mitigation and there cannot be any policy paralysis in management of pandemic irrespective of region, religion, country, race or political system, political will, global collaboration and cooperation, science-led policy decisions, meta-analysis and data management supported by effective communication. Transparency and honesty across nations in sharing information and human resource development shall contribute to better preparedness leading to better mitigation and management of future pests and pandemics across globe. The time has come to appreciate biodiversity and ecosystem services better so as to answer many of our problems including pests and pandemics.

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