Complementing Food and Nutrition Security Using Toxin Minimizing Dry Chain and Integrated Pest Management: A Review

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ABSTRACT

Global programs are involved to improve food and nutrition security in the low-and middle-income countries (LMICs). Increasing agrobiodiversity by maintaining local genetic resources has been proposed to achieve food and nutrition security. However, technology to maintain local germplasms/seed stocks are not available to the small holder farmers. This inability to save seeds translates into 25% annual low moisture food losses to rainfall/floods. As moisture builds up in improperly stored foods, insects, and carcinogenic molds proliferate along with nutrient loss. A dry chain (drying & moisture-proof packaging) could minimize these losses and even enable disaster resiliency. About 40% high moisture foods (fruits & vegetables) are lost due to lack of the cold chain facilities. Additionally, most people in the LMICs ingest artificial toxins daily through high moisture foods due to improper pesticide use. The prevalence of health compromising food toxins in nutritious foods has been complicating malnutrition alleviation efforts in the LMICs. Adopting Integrated Pest Management (IPM) strategies followed by sensitive monitoring could reduce pesticide residues to CODEX standards and enable healthy food systems. A way forward to achieve quality food and nutrition security in the post-Covid-19 era with a particular reference to LMICs like Nepal is presented.

Keywords: Mycotoxin, Pesticides, Seeds, Climate smart, Disasters

1. INTRODUCTION

Global programs are involved in addressing food and nutrition in the developing countries (WHO 2018). Improving nutrition is undoubtedly a challenging interdisciplinary proposition that involves availability and consumption of nutritious food. Covid-19 pandemic has further exposed the vulnerability of food systems in the low- and middle-income countries (LMICs). Green revolution was one milestone towards achieving food security when high yielding crop cultivars were developed (Pingali 2012). However, such cultivars also needed intensive inputs like fertilizers and pesticides. In the pursuit of improving crop productivity, post-harvest management did not get proper attention resulting in about 25% food losses and sub-optimal food qualities (FAO 2011). Saving these losses would undoubtedly improve food and nutrition security during both disaster and normal times (Bradford *et al.* 2018; Dahal *et al.* 2020; Díaz-Valderrama *et al.* 2020; Claes *et al.* 2021).

1.1 Basic Principle

We discuss food and nutrition security strategies based on the moisture content (MC) of the foods. Thus, foods fall under high and low MC groups. In the high MC foods like fruits and vegetables, cold temperature, and high humidity storage (cold chain) is needed to minimize the loss of nutrient and shelf life. In contrast, low moisture products like seeds, grains and nuts need maintenance of low moisture (dry chain) to minimize the loss of viability, nutrients and infestations by molds and insects. We suggest minimizing the anti-nutrients/toxins in both low and high MC foods to complement ongoing food and nutrition security efforts in the LMICs.

2. LOW MOISTURE PRODUCTS

2.1 Seeds for Food Security and Agrobiodiversity

The central role of seeds to increase crop productivity and food security has been recognized globally. Sustainable food systems can be promoted by improving agrobiodiversity (Thrupp 2000). The ability to grow, save and share diversified seeds locally would improve agrobiodiversity and seed resilience (Pautasso *et al.* 2013). Gene bank storage has been envisioned to manage local seed stocks (FAO 2019). However, the expensive cold storage facilities are not available in the LMICs. Although the seed industry has managed seed quality by lowering temperature and relative humidity (RH) using cold storage, the smallholders and community organizations do not have access to such facilities, illustrating the need of alternate, simple, local seed preservation tools to improve agrobiodiversity. Manipulation of RH seems to be an alternate approach for the smallholders to minimize loss of seed quality. For example, corn seeds could be stored for 26 years at a moderate temperature (20ºC) and RH (50%) (Nagel & Börner 2010). Similarly, ultra-dry orthodox seeds stored for 40-110 years at ambient temperatures had high viability (Pérez-García *et al.* 2007; Steiner & Ruckenbauer 1995). Thus, a dry chain (natural or artificial drying to safe MCs, followed by moisture-proof storage) was proposed to save dry products including seeds (Bradford *et al.*, 2018). This technology has been tested in Nepal, India, Bangladesh, Kenya, Thailand, Pakistan, and Guatemala (Afzal *et al.* 2017; Bradford *et al.* 2018; Kamran *et al.* 2020; Guzon *et al.* 2020), indicating scaling up feasibility for securing food grains.

2.1 Securing Food Grains for Disasters

Floods have been damaging dry foods at farms and government stores in the low-lying flood-prone areas in south Asia (BBC 2010; CNN 2020; NAST TV 2017; Poudel *et al.* 2017). These losses have occurred due to lack of awareness about the culprit of stored grain products prompting farmers to store food grains in traditional open or porous containers. Moisture-proof storage is needed to protect foods from floods as practiced in pharmaceutical, processed food and seed industry in the developed countries. Initiating the grain dry chain at harvest time would enable food security during and after disasters like flooding, droughts, locust outbreaks and Covid-19 pandemic (Bradford *et al.* 2018; Dahal *et al.* 2020 ; Díaz-Valderrama *et al.* 2020).

Besides farmers, even the humanitarian donor agencies that are active in disaster relief efforts are unable to protect dry foods from deterioration (Pyakurel 2015), exemplifying the necessity to disseminate the dry chain knowledge nationally or globally. An earlier situation involving poor quality food shipped to Somalia resulted into collaboration between USAID and The Bill and Melinda Gates Foundation and formation of Partnership for Aflatoxin Control in Africa (PACA) (Schmidt 2013) where grain drying efforts are ongoing (ACDI/VOCA).

2.3 Grains Must be Dried Before Packaging

Grains must be dried to suitability to processing or milling before packaging into moisture proof containers. Traditionally, the grains are not dried properly after harvest. The smallholders allow the grains to dry in the open structure or in locally available porous materials, such as low-density polyethylene (LDPE) bags, jute or fertilizer bags, or semi-porous materials, such as metal bins or plastic drums, making low moisture products gain moisture during storage. Before consumption, they dry the grains using traditional "feel" method to determine suitability to processing operations. Recently, moisture meters or humidity strips have been suggested to determine MC more precisely before packaging into moisture-proof containers (Bradford *et al.* 2016).

Natural drying of grains to suitability to processing MC (13-14 %) is possible in major breadbasket regions that harvest 70-80% of grains during fall season. For example, most of the paddy and hill maize are harvested after rainy season during October-November, and wheat is harvested during March-May in Asia. Natural drying of maize in China (Yin *et al.* 2017), wheat in Bangladesh (Nabila *et al.* 2016), maize and cotton in Pakistan (Kamran *et al.* 2020; Bhakhtavar *et al.* 2017) and maize, rice and wheat in India and Nepal have been reported. Analysis of airport weather data in many hinterland locations in Asia shows that natural drying of seed and food products to safe MC is feasible (data not shown). A sample annual weather data for Bhairahawa, Nepal showing the distribution of relative humidity (RH) and high temperature for 2016 as shown in Fig. 1 (Weather Underground 2017). If we had looked at average daily RH values to determine effectiveness of natural drying, the minimum RH values of daytime would have been invisible. The masking effects of average values in seed biological studies have been reported (Still *et al.* 1997).

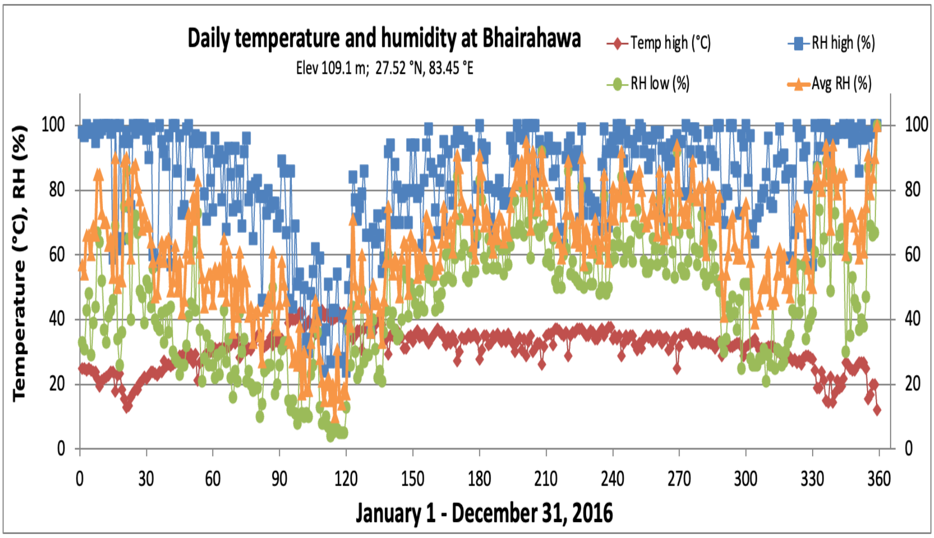

Fig. 1. Distribution of daily maximum temperature◆, maximum humidity ■, minimum humidity● and average humidity▲, during January 1 to December 31, 2016. Note the existence of daytime humidity between 20% - 50% during spring wheat, winter maize and rice harvest periods to enable climate smart dry chain (Weather underground, 2017).

We tested the efficacy of repeated natural drying for 5 days during daytime in May using wheat seed harvested in April 2014 in Bhairahawa, Nepal. USB dataloggers were used to measure RH and temperature by placing inside three 50 kg Triple Layer PICS bags promoted by The Bill and Melinda Gates Foundation (NAF seeds, Patan). RH measurement throughout the day before drying served as the control treatment. Initial and final MC and seed storage life of wheat was calculated using spreadsheet available at http://www.dryingbeads.org/?page_id=84. Seed MC reduced from 9.7 % to 5.5%, predicting high viability of seeds at 25ºC for 3 years (95% estimated initial germination) (Seed System Project, Annual Reports, USAID Horticulture Innovation Lab, 2014; Fig. 2).

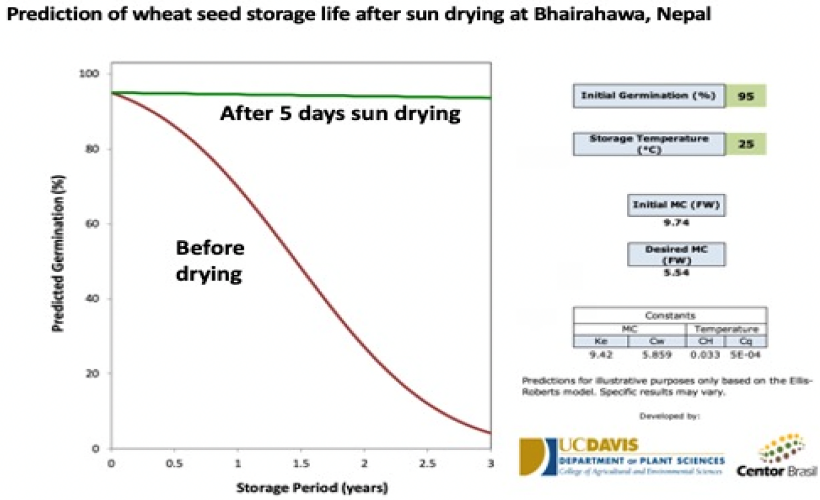

Fig. 2. Prediction of seed storage life (years) of wheat seeds following repeated climate smart drying for 5 days in May 2014 at Bhairahawa, Nepal.

Similar dry weather conditions also exist in India and Pakistan. Wheat is at 10% MC at harvest time in Pakistan, but MC rises to 14% when it reaches to EU markets (FAO 2013). Such low moisture wheat could be packaged into hermetic containers to maintain initial MC. Hermetic packaging prevents weight loss during extreme hot and dry season, prevents moisture increase during the rainy season, avoids insect and mold build up and enables the producers to avail of better market opportunities (Baributsa & Ignacio 2020; Poudel *et al.* 2021). On the other hand, grains harvested in the flood-prone coastal regions such as in southern Bangladesh and southern West Bengal, India, or during the rainy season, should be dried to safe MCs using artificial dryers before packaging into hermetic or airtight/moisture-proof containers (Bradford *et al.* 2018). Small equipment to dry 500-1500 Kgs grains are available in Asia and Africa (Sah *et al.* 2017 & ACDI VOCA). Liquified Petroleum Gas (LPG) drying system is the latest development on small scale drying resources (ADMI). Triple layer Purdue Improved Cowpea Storage (PICS) bags promoted by The Bill and Melinda Gates Foundation and USAID are most convenient to secure the foods by the smallholders (PICS 2020; Baributsa & Njoroge 2020; Poudel *et al.* 2021). However, other moisture-proof metallic or plastic containers (with seals) or tunnels could also be used to store properly dried food products (Darby & Caddick 2007; Bartosik 2012).

2.4 Consequences of Improper Drying

Several distinct damages occur in the postharvest stage of improperly dried seeds and grains.

2.4.1 Seed Viability

Improperly dried seeds begin to lose viability as it moves downward on the death curve. Such viability loss can be measured by traditional germination assays. The seed industry regulates both temperature and RH of the storage to minimize viability loss. The Vienna oat seed sample (1877) stored at ultra-dry MC (3.12%) at ambient temperature that maintained high viability after 110 years, is a classic example of moisture modulating seed viability. High viability of several seeds was reported after 26-39 years at moderate temperatures (Nagel & Börner 2010; Pérez-García *et al.* 2007).

2.4.2 Molds and Insects

Molds and insects proliferate in improperly dried and stored grains in traditional structures. Toxigenic molds, such as Aspergillus species, in grains are of primary concern in the resource-rich countries. However, LMICs have yet to implement concrete programs to minimize mold toxins in their food systems. For example, UNICEF and European Union partnered to implement multisectoral nutrition program (MSNP) to improve nutrition of children and women in 28 districts in Nepal (UN OCHA 2016). However, researchers have reported that 94% pregnant women in Sarlahi and Banke in Nepal had mycotoxin (aflatoxin) markers in their blood (Groopman *et al.* 2014; Andrews-Trevino *et al.* 2020). Clearly, MSNP is being implemented in districts where the need of aflatoxin management in staple foods has yet to be realized (Scaling Up Nutrition 2017). Aflatoxin epidemics have occurred in India and Africa and the foods/feeds are widely contaminated with mycotoxins (Kensler *et al.* 2011; Darwish *et al.* 2014; Schmidt 2013; Atherstone *et al.* 2014; Wild 2010). Aflatoxin B1, Class I carcinogen, has been linked to liver cancer, and hence other health effects are an obvious concern of IARC/WHO (Reddy *et al.* 2009; Wild 2010; Wild *et al.* 2010; Zain 2011; IARC 2012; Ochieng *et al.* 2013; Groopman *et al.* 2014; Wild *et al.* 2015). Regulatory limits for major mycotoxins in foods have been reviewed (Alshannaq & Yu 2017).

Molds and insects co-develop in improperly dried grains when stored in open or porous containers. It is recommended that maize be dried within 3-5 days to about 18% MC for shelling and to 13%-14% MC to enable processing operations that also minimize the proliferation of carcinogenic storage molds that produce secondary metabolites called mycotoxins (notably aflatoxins) (FAO 1992). Toxigenic molds begin to infest the crop at pre-harvest stage and further proliferate in storage in absence of proper drying of the grain. Unsafe level of mycotoxins in maize grains has been detected at harvest time in Africa that receives biannual rainfalls (Meridian Institute 2015). Biological control of toxigenic Aspergillus species using a mixture of country specific atoxigenic strains to outcompete the former (Aflasafe) (Bandyopadhya *et al.* 2019) has increased poultry performance (Aikore *et al.* 2019). Thus, biological control should be an essential part of good agricultural practice (GAP) in regions where unsafe level of mycotoxins are present at harvest time. Whether Aflasafe is needed in south Asia is unknown as only a few studies have looked at mycotoxin prevalence at crop harvest time. Studies have rather focused on mycotoxins in food and feeds during storage in Nepal (Koirala *et al.* 2005; Desjardins *et al.* 2000; Khadka *et al.* 2000; Poudel *et al.* 2021) and in India (Singh & Srivastav 2011; Singh 2019). Even processed foods and baby food products are contaminated with mycotoxins in neighboring countries of Nepal (Mushtaq *et al.* 2012; Naz *et al.* 2019; Mehta *et al.* 2020). Such food quality issues could account for widespread mycotoxin marker prevalence in hospital workers and patients in Banepa (Dennings *et al.* 1990) and in pregnant women in Banke and Sarlahi (Andrews-Trevino *et al.* 2020; Groopman *et al.* 2014) in Nepal. A 60-year review of aflatoxin prevalence in Kenya, Africa further highlights the need of mold minimization in food/feeds that affects human health (Omara *et al.* 2021). Combined with additional aflatoxin marker studies in pregnant women in Gambia, Africa (Castelino *et al.* 2014), there is urgent need to minimize natural mycotoxins that contaminate about 25% of food grains globally (Alshannaq & Yu 2017).

Several global forums are trying to minimize the prevalence of natural mycotoxins in food/feed systems using different tools. Rapid drying to the processing MC has been proposed to minimize the development of storage mycotoxins. Drying feed mix containing 55% maize to 11% MC in India prevented mold infection up to 30 days (Singh *et al.* 2017), further supporting drying interventions suggested by International Agency for Research on Cancer (IARC) (Wild *et al.* 2016; Bradford *et al.* 2018). Recently, Cold Plasma treatment has also been suggested to manage molds and mycotoxins in food/feed but its effect on other nutritive properties have yet to be addressed (Pankaj *et al.* 2020). Protective cultures of yeast and bacteria are also being tested to minimize aflatoxins in food products (Delgado *et al.* 2018). Feed additives to adsorb the mycotoxins in the gut system are also used to minimize the adverse effect on animal nutrition (Engormix 1999). A microbial metabolite, equol, has been shown to reduce the adverse effect of mycotoxin zearalenone in vitro culture of prenatal ovine follicles (Silva *et al.* 2019). Zinc and Vit E supplementation to aflatoxin contaminated diet ameliorated the adverse effects on performance of the broiler chicken (Sharma *et al.* 2014; Singh *et al.* 2016). The animals feeding on mycotoxins contaminated feed can transfer the toxins to the proteinaceous dairy and meat products (Giovati *et al.* 2015). Furthermore, the animals exhibit several organ-specific health effects (Mahmoud & Leil 2013; Benkerroum 2020), suggesting the need of combined preventive approaches involving biological control and dry chain. There is prediction that mycotoxin problems will shift to current cooler climates from tropical regions due to climate changes and further damage stored dry products (Russel *et al.* 2010).

Few stored-grain insect pests are major co-culprits of stored dry products and inflict differential damage to grain nutrients (Stathers *et al.* 2020), illustrating the urgency to manage both storage molds and insects. Drying and pesticide-free hermetic storage minimized both insect and mold build up during storage (Ng'ang'a *et al.* 2016; IRRI Super Bag). Hermetic bags were also effective to manage the notorious storage larger grain borer (*Prostephanus truncates* (Horn)) at high temperature (38ºC) in a 3-month study (Singano *et al.* 2020). An update on the application and adoption of the hermetic bags is available (Baributsa & Ignacio 2020; Baributsa & Njoroge 2020). Low temperature (15ºC) is also employed to control storage insects, but molds subsequently proliferate at high grain MCs (WaTTAg Net. 2016). Cultivars with resistance to both insects and fungal diseases are developed in China (Xu 2013). However, a dry chain would still be needed in the storage of such grains to minimize the loss of nutrients.

2.4.3 Nutrient Losses

Nutrients were lost gradually when maize was allowed to lose MC naturally during 6 months in different elevations in Ethiopia (Garbaba *et al.* 2017). However, when maize was dried to 15% MC and insects were controlled using pesticides annually, nutrients were maintained for 4 years in the barn near Beijing. Furthermore, these quality grains in feeds positively affected growth rate and meat quality of the chickens. It is worth noting that the initial drying avoided mold development and air circulation in the barn further reduced MC to 11.1%- 12.4% (Yin *et al.* 2017). There was minimal change of protein and lipid contents in jute seeds stored for 12 months when dried to 9.5% MC in tin containers compared to 14% MC in earthen containers in Bangladesh (Haque *et al.* 2015). Although MC was not checked after storage in jute seed nutrients assays, another 8-month wheat storage experiment showed that tin containers maintained lower MC than earthen and plastic containers (Nabila *et al.* 2016), implying that the lower MC was responsible for the least changes in nutrients in stored jute seeds.

Long-term breeding strategies to combine mold-resistance with other traits could also be pursued (Kaisera *et al.* 2020; Thakare *et al.* 2017). Thus, breeding for triple resistance to mold, insect infestation and nutrient loss would be feasible and such grains might be resistant to damage by the floods. It is noted that such triple effects of moisture on mold and insect infestations and nutrient loss in grains have yet to be realized by the researchers, donors, and national governments (Global Grand Challenge 2018). Until seeds of such resistant crops are available, immediately implementable technologies need to be used to save massive food and nutrient losses.

Drying and hermetic storage have been identified as key tools to minimize seed and food losses (Bradford *et al.* 2018; Dahal *et al.* 2020; Díaz-Valderrama *et al.* 2020). Based on moisture effects identified above on seed viability, mold and insect proliferation and nutrient losses, food management programs in LMICs need to embrace moisture and nutrition sensitive tools in postharvest food/feed management (NDTV 2013; Cartalucci 2014; UPI 2013; Reuters 2014; Shen Zhen Daily 2015; Epoch Times 2015). A Zero Hunger Initiative in Nepal has identified postharvest management as one of the pillars to achieve food and nutrition security (Nepal Planning Commission 2016). Yet, the annual floods continue to damage stored staple foods that are major source of nutrients.

2.4.4 Nutrition Diversity

One additional method to improve nutrition is to diversify the source of nutrients. We suggest introducing nutritious quinoa (*Chenopodium quinoa* C.L.) in currently cereal dominated farming systems in LMICs. Quinoa is a crop of much potential for global impact due to its exceptional nutritional properties, resistance to adverse environment and adaptability to agro-ecological extremes (Williams 1995; Didier *et al.* 2016; Bhaktavar *et al.* 2019). Due to its excellent balance of amino acids, vitamins and minerals, the malnourishment in LMICs could be minimized and the economic status of smallholders could be improved through exports as well. We should also help preserve and promote nutritious but neglected climate resilient local cultivars of buckwheat (*Fagopyrum esculentum* L.), amaranth (*Amaranthus viridis* L.) and millet (*Paspalumscro biculatum* L.) (Williams 1995). Like quinoa, these crops yield low moisture grains, require low input, and suffer low pest attack that will help to minimize dietary food toxins in LMICs.

3. HIGH MOISTURE PRODUCTS

High moisture foods like fruits and vegetables are major source of nutrients including essential vitamins, minerals, and antioxidants. As these foods are also major source of artificial toxins/pesticides to most people in the LMICs, strategies to minimize loss of nutrients as well as pesticide residues should be implemented.

3.1 Nutrient Loss and Pesticide Residues

Cold chain is recognized global method to minimize about 40% loss of high moisture nutritious fruits and vegetables (Raut *et al.* 2019; FAO 2011). The cold chain is increasingly being realized in the LMICs mainly through the community groups and food cooperatives. However, the smallholder farmers mostly rely on the chemical pesticides to control insect pests and diseases to produce these nutritious foods (Pretty 2005). Although the pesticide usage in LMICs is far below than in high income countries, the risks related to pesticides are much higher in the former because of improper application methods (Schreinemachers & Tipraqsa 2012; Sharma *et al.* 2013). Clearly, the management of food toxins is of primary concern in the resource-rich countries, but the intervention tools to minimize their prevalence in LMICs have yet to be used (Aryal *et al.* 2014). Pesticide residues issues are prevalent in many countries, including Nepal (Li *et al.* 2017; Bhandari *et al.* 2020; Kapeleka *et al.* 2020). Mass protests erupted in 2019 in Nepal due to pesticide residue concerns in foods imported from India (Dahal 2019). Notably, India has promoted pesticide residues minimization programs in the state of Sikkim (FAO 2018). From nutrition point of view, such efforts should be carried out in all states in both countries that trade in food products heavily through the open border. Indiscriminate pesticide use directly or indirectly affects the biodiversity, environment, and health. After using the interventions, sensitive systems should further monitor pesticide residues in foods to minimize risks to human health (Pang *et al.* 2020).

4. INTEGRATED PEST MANAGEMENT AND BIODIVERSITY

Integrated Pest Management (IPM) is an important approach to minimize pesticide residues in food products (Integrated Pest Management Innovation Lab 1993). It combines possible alternative pest management approaches and gives low priority to the synthetic pesticides (Stenberg 2017). IPM has been successfully implemented in many countries to reduce over-reliance on chemical pesticides and environmental impacts and improve biodiversity. The effectiveness of IPM technology to reduce artificial pesticide residues to CODEX standards (CODEX ALEMENTARIUS) has been tested in Nepal (Bhandari *et al.* 2019; Bhandari *et al.* 2020). Implementing IPM throughout Nepal could address current consumer concerns (Kathmandu Post 2020). This approach uses the ecological, social, and economic aspects of pest management like scouting of pests and natural enemies and decisionstake place based on the agro-ecological situation and recommends 'soft' pesticides on a 'needs' basis (Barzman *et al.* 2015). Excess pesticide use is associated with decline of pollinators, reduced biodiversity (variety of life in an ecosystem), degradation of soil fertility, eutrophication of rivers and lakes, air and water pollution and health problems (Geiger *et al.* 2010). The decline of biodiversity not only affects ecosystem functions (EF) but also increases its instability (Tillman *et al.* 2006), affects crop productivity (Letourneau & Altieri 1999) as well as human well-being (Cardinale *et al.* 2012).

IPM promotes habitat management and reduces pest pressure in agricultural fields, improves multiple ecosystem services and sustainable agriculture (Gurr *et al.* 2017) and enables organic farming. Such improved biodiversity drives the agro-ecosystem services and provides food, shelter, fresh water, and clean air (Joshi & Chouhan 2000). Rich biodiversity increases the density and diversity of natural enemies such as predators and parasitoids, improves the activity of pollinators and finally supports sustainable agriculture. Our agricultural production systems depend highly on ecosystem services that help to improve conservation biological control (CBC) followed by pest control, enhanced pollination, carbon sequestration, soil fertility improvement, nutrient cycling and hydrological services (Altieri 1999). Simple vegetative diversification on farms influences herbivore, predator, and pollinator activities by visual or chemical cues (Hokkanen 1991), acts as a barrier to movement (Perrin & Phillips 1978) and creates a different volatile profile in crop fields (Finch & Collier 2000). Examples of habitat management in agricultural fields include trap cropping (Wan *et al.* 2016), cover cropping (Storkey *et al.* 2015), and the use of the flower strips (Gurr *et al.* 2017) that can facilitate habitat pest management activities in an agro-ecosystem.

5. CONCLUSION

There is need of implementing dry chain and IPM interventions to enable safe food systems in LMICs. For high moisture foods, additional use of a cold chain could minimize nutrient and about 40% productivity losses. For low moisture foods, a dry chain would increase productivity by about 25% and minimize p natural toxins, enable local seed/ food systems, and improve biodiversity and disaster resiliency. Implementing dry chain and IPM in crops and communities could minimize economic, health and environmental risks to the farmers and consumers. A continuous sensitive toxin monitoring of both domestic and imported foods is an integral part to build consumer confidence on local food products, enable export of quality foods, promote tourism, and improve livelihoods of smallholder producers.

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