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Review Article

Plant protection measures to promote organic farming in Nepal: prospects and challenges

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ABSTRACT

Organic farming is a production system that relies on ecosystem management rather than external agricultural inputs to sustain the health of soils, ecosystem and organisms. This needs enough organic plant protection measures and biological fertilizers by eliminating synthetic pesticides and fertilizers. An attempt was made to review current plant protection measures for organic farming in Nepal. Though some insect pests and diseases are very hard to control without the use of chemical pesticides, this is high time to produce agriculture products organically. There is ample prospect of organic production in Nepal utilizing traditional knowledge of Nepalese farmers and existing agri-biodiversity. The paper is focused on best utilization of local natural resources, indigenous knowledge and bio-control agents for plant protection in organic agriculture. The information related to organic plant protection measures are collected from various sources and are grouped. The authors have listed technologies on organic plant protection measures in Nepal and made some suggestions to improve the organic farming of the country.

Keywords: Organic, protection, pests, predators, parasitoids, bio-pesticide, safe

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INTRODUCTION

Organic farming is a holistic production system that oppose or largely eliminates the use of synthetic materials such as chemical fertilizers, growth regulators and pesticides, and promotes crop rotation, green manures, legumes, animal manures, crop residues and biological pest control. Organic farming support and enhance agro-ecosystem health including biodiversity, biological cycles and soil biological activity, using agronomic, biological and mechanical methods (FAO/WHO, 1999). Historically organic farming was the way of living for Nepalese agriculture but after green revolution conventional farming came

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into practice. The government's priority is to boost the agricultural production by maximizing inputs such as fertilizers, seeds, chemical pesticides etc. As a result, chemical pesticides and fertilizers are imported in increasing rate (PQPMC, 2021; MOALD, 2021).

Being relatively easy and quick method, chemical method of plant protection has played a major role to overcome pest problems in agriculture. The import of pesticides in the year 2020/21 was 783.2 mt which was 13% higher than the year 2019/20 (PQPMC, 2021). The average consumption of pesticide in Nepal is 0.396 kg a.i/ha. Although the consumption is comparatively lower than other countries such as India (0. 481 kg/ha), China (2.0–2.5 kg/ha), Japan (10.8 kg/ha), Europe (1.9 kg/ha) and USA (1.5 kg/ha) (Sharma, 2019; Aryal et al., 2021), the consumption in commercial agricultural areas are much higher than the national average. The pesticide consumption is significantly higher in vegetables and other commercial/cash crops compared to the cereal crops (PQPMC, 2021).

Farmers are frequently using broad spectrum synthetic chemical pesticides to manage crop pests and they hardly care about prescribed waiting period before crop harvest (Maharjan *et al*., 2004; Sharma, 2015). The misuse and over-reliance on chemical pesticides results pesticide tolerance in crop pests (Georghiou, 1983; Baker, 2011; Lou, 2013) which demand higher doses and frequent application of pesticides causing economic, human health and environment losses. The impact of insecticide resistance and the reduction of natural enemy populations that results in pest resurgence and secondary pest outbreak has increased the burden for farmers (Pimentel, 2005). Higher concentration of insecticides residues, than the permissible limit in different consumable food items are causing human health issues (Sharma, 2015; Margni *et al*., 2002). Pesticides residues have not only been observed in food but are also found in soil and water harming the whole ecosystem (Tsaboula *et al*., 2016). Bhandari *et al* 2021 reported residue of different insecticides such as chlorpyrifos, profenofos and imidacloprid even DDT (banned in 2001) in soil samples of commercial vegetable fields which founds to be toxic to different soil organisms. In this sense organic farming may be best solutions to minimize the injudicious use of chemical pesticides and sustaining the crop yields, safeguarding human health and environment.

Organic agriculture sector is gaining momentum in Nepal. About 2, 05,438 producers are involved in organic farming producing organic product in 2, 73, 614 ha of land (HASERA, 2022). National standards have been established and endorsed by the government, and working guidelines are being developed based on the standards set by International Federation of Organic Agriculture Movements (IFOAM), an international umbrella organization for organics established in 1972 (IFOAM, 2008). Until year 2022 fifty agriculture companies and cooperatives are certified from foreign organic certification bodies and thirty-one companies and cooperatives are certified from Organic Certification Nepal (OCN) (HASERA, 2022). Two certification systems (Internal Control System and Participatory Guarantee System) are being developed by Nepal, both of which will serve as an important instrument for taking advantage of the international and domestic markets. The latter is a certification scheme particularly for small farmers whose products are of high demand in the local market, but who cannot meet the high cost of certification. Government of Nepal has given priority to organic agriculture. National Organic Agriculture Accreditation body (NOAAB), the National Coordination Committee for Organic Agriculture Production

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and Processing System (NCCOAPPS), and the policy document such as Organic Agriculture Promotion Mission Program Implementation Procedure 2019 has been recently formulated in Nepal. Ministry of Agriculture and Livestock Development has been supporting for the certification of exportable organic produce to encourage the producers. Agribusiness promotion policy also envisaged the plan to register local and indigenous knowledge and technology for its use in agriculture. Karnali Province has declared organic state since 2019. Indigenous and local crop production and marketing has been promoted by Gandaki Province. Also demand for organic products is growing in domestic and international markets. An increase in purchasing power, education and awareness about health and quality of organic foods and the willingness to pay for healthy foods among consumers, have increased the demand for organic vegetables in urban areas. However, one of the main difficulties of organic agriculture is very limited or almost lack of organic inputs like seeds, bio-fertilizers and bio-pesticides in Nepal. Farmers engaged in organic agriculture are not confident because of some pests and diseases which are very hard to control without use of chemical pesticides.

Crop pests are considered to be major yield depleting factors in agriculture. Approximately 20 - 25 percent of the potential yield of food crops are being lost annually due to damage by pests (Neupane, 2002). Though some insect pests and diseases are very hard to control without the use of chemical pesticides, this is high time to produce agriculture products organically. The role and responsibility of plant protection agencies has become more challenging in organic agriculture as they need enough plant protection measures other than the use of chemical pesticides. It is important to know what plant protection measures are available to use in organic agriculture and what are the prospects and challenges of organic plant protection measures to promote organic farming in Nepal. Therefore, this article attempts to examine the existing situation of organic plant protection measures for organic farming, its prospects and challenges in Nepal.

Organization involved in promotion of organic plant protection measures in Nepal

Some public and private organizations are being involved directly or indirectly to promote organic plant protection measures in Nepal. These organizations mainly work in the area of research, registration of bio pesticides, formulation of bio pesticides, production of bio pesticides, extension, awareness, training, input supply (bio-pesticides), subsidy program etc. The research works are mainly performed by Nepal Agricultural Research Council (NARC), National Academy of Science and Technology (NAST), private companies, cooperatives and different teaching institutes under different universities. National Entomology Research Centre and National Plant Pathology Research Centre of Nepal Agricultural Research Council is producing and maintaining various kind of entomopathogens and biocontrol agents in its laboratory (NERC, 2022; NPPRC, 2022), conducting different experiments on identifying botanicals having pesticidal effect (Paneru and Khadge, 2007; Giri et. al., 2012), several research in cultural method of pest management (push-pull technology), effectiveness of different traps etc. The Plant Quarantine and Pesticide Management Centre (PQPMC) solely work in registration of bio-pesticides and giving permit for formulation of bio pesticides. The center also works for awareness and training program. The seven plant protection lab under seven provincial government work in maintenance of biological control agent, conducting applied research, conducting awareness program, training, input supply (bio-pesticides) in subsidy etc. Currently two private companies Agricare and Prarambha Biotech are found conducting research and production of bio pesticides in Nepal. Three bio-

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pesticide production community resource center in Kavrepalanchowk, Banke and Kailali are producing *Tichoderma viridae* which highlights the government interest and support in the bio-pesticide production and use. Different NGOs/INGOs such as Sustainable Soil Management Program (SSMP), HELVETAS, HASERA, EcoHimal, LIBIRD, HEACOP, Nepal Permaculture Group (NPG) and FORWARD are working in extension, awareness, training, supplying bio-pesticides in subsidy etc. Teaching institute are involved in developing curriculum along with conducting research on organic agriculture.

Existing plant protection measures for organic farming

Various plant protection methods and practices such as use of physical, mechanical and cultural means, tolerant cultivars of various crops, biological control agents (predators, parasites and pathogens), botanicals and behavior modifying substances (attractants and repellants) are used to manage crop pests in organic farming. Since long time, cultural, mechanical, physical measures along with various organic products, such as animal urine, cattle dung, animal milk, soaps, wood ash, botanicals and oils are being used by the Nepalese farmers for managing various kinds of pests in agriculture (Neupane, 2003). Ansari et al. (2013) also highlighted the extent and potential use of bio-pesticides for crop protection in Nepal which exclusively revealed some successful biological control program that can be good example for future work. However, the use of formulated bio pesticides is new for Nepalese farmers. First registration of bio pesticides in Nepal was in year 2001 and first registered bio pesticide was commercial product of *Bacillus thuringiensis* (PRMS, 2006). In year 2005 two more bio pesticides (*Trichoderma viridae and Beauveria bassiana*) were registered and imported for testing and the import permit was for one year (PRMS, 2006). Plant protection system for organic farming is still in preliminary stage in Nepal. There are three categories of Nepalese organic farmers in context of plant protection 1) do nothing for pest control and harvest what has left; 2) use their own local resources and knowledge for pest management; 3) use their own knowledge, local resources along with available external resources (bio pesticides and herbal product etc) by knowing what are allowed to use as per organic certification standard and guidelines.

Cultural and mechanical method

This method of crop pest management had started since human being started to cultivate the crops. Cultural methods used to enhance crop health and prevent weed, pest, or disease problems through management practices without the use of substances, examples include the selection of appropriate varieties and planting sites; proper timing and density of plantings; irrigation, balance use of manures, crop rotation, mixed cropping, intercropping (push-pull), sanitation, weeding, destruction of crop refuge, pruning, thinning, mulching, cover crops, mowing, tillage, use of resistant varieties and extending a growing season by manipulating the microclimate with green houses, cold frames, or wind breaks. Mechanical method includes use of traps (light traps, lure traps, sticky traps and rat traps), barriers (banding of tree trunk, wire gauge screenings, trenching), hand picking of egg masses and their early stage larvae; light and sound; shaking or beating of whole plant or branches. Some research findings related to use of cultural (Table 1) and mechanical methods (Table 2) are listed.

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Table 1. Research findings on cultural method in organic pest management

Insect pests	Research findings	References
Eggplant fruit and shoot borer (EFSB), *Leucinodes orbonalis* Guenee	Transplant eggplants in early June in Kathmandu valley.	E. D., 1997
	Grow barrier crops such as maize around the eggplant crop fields.	
	Use nylon net barrier over the nurseries to prevent spreading of insect from nursery to main fields.	Paneru and Giri, 2011
	Create physical barrier using 2 m. high nylon net around eggplant growing field to check entry of EFSB moths into the eggplant field from infested fields.	Paneru and Giri, 2011
	Adopt clean cultivation practices.	Paneru and Giri, 2011
	Avoid continuous cultivation of eggplants in the same fields.	
	Grow moderately tolerant eggplant varieties, such as Green Long, Pusa Kranti, Pusa Purple Long.	Paneru and Giri, 2011
	Grow location specific varieties moderately tolerant to borer such as Pusa Kranti and Nurki at Kathmandu valley, Lurki at Baglung and Parbat areas, Pusa Long at Dhading, Green Long and Pusa Kranti at Tarahara areas of Sunsari district.	E. D., 1997
	Grow eggplant varieties with slender shape fruits as the round shape fruits are much susceptible to borer.	Neupane, 2002
Potatoes tuber moth (PTM), Pthorimaea operculella Zeller on tubers and plants	Plant non-infested potatoes.	Paneru and Giri, 2011
	Follow deep planting (up to 10 cm) of potatoes in the area vulnerable to PTM occurrence every year.	
	Give earthing up for plants with large quantity of soils against PTM.	
	Irrigate potato crop field timely as required so as to avoid egg laying by PTM during tuber formation stage.	
	Harvest tubers before dying or yellowing of potato plants.	
	Follow clean harvesting without left over and potato hauling in the fields.	
	Take away all plant debris from the field before or after harvesting the potatoes to reduce population build up in following season.	
Tomato fruit worm *Helicoverpa armigera* Hubner	Carry deep plowing during summer season to expose the pupae on the soil surface so as to destroy by natural enemies or dehydrated by scorching sunlight.	NARC, 1999
	Intercrop non-preferred host plants such as barley, wheat, coriander and linseed with tomato.	Paneru and Giri, 2011
	Plant yellow colored and tall type of marigold (*Tagetes spp*.) or Calendula as a trap crop with tomato (1 row trap crop: 5 rows tomato). Eggs laid by *H. armigera* on flowers of trap crops could be destroyed through suitable means.	
Whitefly, *Bemisia tabaci* Gennadius	Avoid excessive dampness and dark in the crop growing environment in poly-houses.	Paneru and Giri, 2011
	Avoid transplanting of whitefly infested seedlings.	
	Rogue out the virus affected plants as soon as the symptoms are observed.	
	Intercrop non-preferred crops such as wheat, barley with main crop to reduce whiteflies infestation.	
	Avoid application of excess quantity of nitrogenous fertilizer as the succulent and tender plants are vulnerable to whitefly.	Bhandari, et. al., 2007
Maize borer, *Chilo partellus* Swinhoe, on maize	Use of moderately resistant varieties like, Rampur-1, Arun-1 & Rampur Composite	NARC, 1999

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Diamond back Moth,*Plutella xylostella* Linnaeus	Intercrop 2 rows of mustard as a trap crop after every 25 rows of cabbage to supply continuous foliage until maturity of cabbage. Mustard is its most preferred host. Intercrop tomato with cabbage (emission of volatile compounds by tomato inhibits egg-laying by moth). Plant one row of cabbage and one row of tomato (cabbage is planted 30 days later than the tomato).	Neupane, 2002
Rice/Maize borers complex	Collect and destroy all the rice stubbles at the time of first plowing after harvesting. Dip all rice stubbles after harvest in the field stagnating water for 5-7 days to kill larvae and pupae. Clip tips (2.5 – 3 cm) of the seedlings just before transplanting to prevent egg laying near the tip of the leaf (particularly in nursery). Remove plants having symptoms of dead hearts, destroy egg masses and remove infested seedlings from nursery. Synchronize planting time over a large area. Increase seed rate of maize by 50% for sowing in the borer endemic field to compensate plant population after borer infestation.	Neupane, 2002
Root knot nematode in Tomato	Tomato plants grafted in wild eggplant (*Solanum sisymbriifolium*) reduce root knot nematode.	Baidya et al, 2011
Stalk rot (*Sclerotinia sclerotiorum*)	Mulching with rice straw is effective to reduce incidence of stalk rot in cauliflower	Timila & Shrestha, 1999

Table 2. Research findings on mechanical method in organic pest management

Insect pests	**Research findings**	**References**
Eggplant fruit and shoot borer (EFSB), *Leucinodesorbonalis* Guenee	Cut and destroy wilted and borer damaged fruits and shoot. Collect and destroy borer infested flower buds and fruits during each harvest to prevent the migration of caterpillar from fruit to fruit. Pinching off weathered shoots immediately when it appears in the plant.	Shivakoti, 2000
Melon fruit fly, *Bactrocera cucurbitae* Coquillett	In kitchen garden (Small scale), wrap non-infested fruits by small piece of muslin cloths for 10-15 days to escape egg laying in pumpkin, cucumber, snake gourd, Zukuni etc. Collect all infested fruits from the fields and destroy them in a safe place (0.5 m. deep pit)	Paneru & Giri, 2011 Paneru & Giri, 2011
Potatoes tuber moth (PTM), Pthorimaea operculella Zellerin store and field	Submerge table potatoes in water for 24 hours and shade dried before storage. Dispose all discarded tubers by burying under soil to minimize food source for PTM. Take away harvested tubers immediately from the field in the store room or cold store for storage. Avoid mixing together the old lot and new lot of tubers in the same store. Store potato tubers inside the nylon net cover to avoid contact of PTM with tubers for oviposition. Avoid transportation of PTM infested material from one place to another. Store potato in cold storage (<5^0C temperature).	Paneru & Giri, 2011
Aphids, *Lipahis erysimi* K., *Brevicoryne brassicae* L., *Myzus persicae* Sulzer	Install yellow pan trap with 1% kerosene water or yellow sticky traps (coated with adhesive or sticky glue) at crop height in the fields.	Paneru & Giri, 2011
Tomato fruit borer, *Helicoverpa armigera* Hubner	Collect and destroy infested fruits weekly to reduce the borer incidence and prevent migration of caterpillar from fruit to fruit. It is comparatively more beneficial in the beginning of	Paneru & Giri, 2011

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	infestation.	
Diamondback moth, *Plutella xylostella* Linnaeus	Collect and destroy all the remaining during harvest of crops to prevent buildup of second generation population.	Paneru & Giri, 2011
	Collect and destroy larvae mechanically in early stage of infestation to check their population builds up.	Paneru & Giri, 2011
Tobacco caterpillar *Spodoptera litura* Fab.	Collect and destroy egg masses and gregarious feeding larvae mechanically. It needs regular scouting to locate egg masses and leaf skeleton.	Paneru & Giri, 2011
Whitefly, *Bemisia tabaci* Gennadius	Install yellow sticky traps (coated with adhesive or sticky glue at crop height) for monitoring and mass trapping of adult white flies.	Paneru & Giri, 2011
Rice/maize stem borer complex	Install light traps in the rice field to reduce population of moths.	Neupane, 2002.

Botanical method

Nepalese farmers have a long tradition of using indigenous plant materials to protect standing crops and post-harvest agricultural products. Nepal possess more than 324 plant species having pesticidal properties, out of them 21 plant species are considered very effective against insect pests (Neupane, 2003). The use of Neem (*Azadirachtaindica A. Juss*) products is found most promising among the plants with pesticidal properties to manage broad range of crop pests. The Neem products are used as insecticide, fungicide, nematicide and weedicide. A total of 56 commercially formulated products of Neem with the active ingredient Azadirachtin has been registered by the Nepal Government to use in organic agriculture (PQPMC, 2021). Azadirachtin dissolves in water so neem seed kernel extract can be sprayed on plants after mixing a little amount of powder soap or a plant sticker (Neupane, 2006). The neem oil cake if applied in the soil provides nitrogen to the crop as well as controls nematodes and different fungi parasitic to crop plants (Neupane, 2006). The crude form (dust) of Neem fruits, sweet flag (*Acorus calamus L.*) rhizome, Boke timur fruits (*Zanthoxyllum alatum Roxb)* and rape seeds (*Brassica campestris* var toria) are proved to be effective against weevils (*Sitophillus spp., Burchus spp*. and *Callosobruchus spp*.) in stored grains. The β-asarone is an active insecticidal content in the sweet flag rhizome (Paneru et al 1997). Similarly, fermented (1 – 4 weeks) cocktail mixture of fresh leaves, twigs and seeds of different botanicals such as Neem, Chinaberry, Malabar nut, Indian privet, Chrysanthemum, Tobacco, Elderberry, Siltimur, Boketimur, *Mentha*, *Ageratum*, Hemp, Lemon, Custard apple and Soapberries have shown promising response to manage vegetable insect pests and disease (Neupane, 2003). Reduction of bacterial wilt of tomato by *Zanthoxylum* extract (Timila and Shrestha, 2001), reduction of powdery mildew and downy mildew of cucumber by nettle leaf extract in cattle urine (Gautam and Gauli, 2006) are documented. Some research findings related to use of botanicals are listed in Table 3.

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Table 3. Research findings on botanical method in organic pest management

Insect pests	Research findings	References
Eggplant fruit and shoot borer (EFSB), *LeucinodesorbonalisGuenee*	Spray crude neem seed extract (@ 5%) or neem based pesticides such as Margosom (Azadirachtin 0.03%) or Neemarin or Biomultineem @ 5 ml per liter water.	Shivakoti, 2000
Melon fruit fly, *Bactrocera cucurbitae* Coquillett	Use extracts of neem fruits to repel female flies. Use zinger extract to kill fruit flies. Use a cotton pad treated with 0.25 ml of Tulsi (*Ocimum sanctum*) leaves extract in ethyl acetate for luring and trapping the fruit flies. Apply the protein bait sprays (2 ml malathion 50% EC + 25ml hydrolyzed protein + 1 liter water) at few spots in a field to kill the flies attracted.	Paneru & Giri, 2011 Paneru & Giri, 2011
Potato tuber moth (PTM) *Pthoremia operculella Zeller* on potato	Treat potato tuber with sweet flag stolen powder @ 2 g per kg.	Giri et. al.,2012
Aphids, *Lipahis erysimi* Kaltenbach, *Brevicoryne brassicae* Linnaeus, *Myzus persicae* Sulzer	Spray aqueous extract of Malabar-nut *Justicia adhatoda* leaves/stem or chinaberry *Melia azedarach* fruits or seed pomace of *Brassica compestris* at 1:4 ratio (W/V) to protect vegetable crops. Spray aqueous extract of leaf/stem of *Mentha arvensis* (200 g per 1.33 Lof water) to manage mustard aphid. Spray aqueous extract of leaf/stem of *Artimisia vulgaris* (200 g per 1.33 L of water) to manage potato aphids.	Vaidaya, 1993 Vaidya, 2000a
Cabbage aphids on Cabbage	An aqueous fraction of aconite root at 1% concentration.	Shrestha, (1999)
Tomato fruit borer, *Helicoverpa armigera* Hubner	Spray aqueous extract of crude neem seed (50 g seed per L water) or neem based pesticides such as Margosom or Neemarin or Biomultineem @ 5 ml per L water.	Shivakoti, 2000
Tobacco caterpillar, *Spodoptera litura* Fabricius	Spray neem based pesticides such as MargoSom (Azadirachtin 0.03%) @ 5 ml per L water.	Paneru & Giri, 2011
Whitefly, *Bemisia tabaci* Gennadius	Spray neem based insecticides such as altineem @ 5 ml/L water to manage early instars of whitefly.	Paneru & Giri, 2011
Cabbage butterfly, DBM and Cabbage aphid on cole crops.	Water extract of neem seeds, tobacco stem and leaves, and chinaberry seeds and leaves.	Joshi, 1994.
Red ants, *Dorylus orientalis*, on potato	Soil drenching of aqueous solution of Azadirachtin (0.00045%) near plant stems @ 100 ml /plant at tuber initiation and 30 days after the first treatment	Joshi, 1998
Cabbage butterfly, Soybean hairy caterpillar, Tobacco caterpillar and DBM on cabbage	Crude water extracts of green neem leaves (*Azadirachta indica*), Chinaberry *(Melia azedarach*), malbar-nut (*Justici aadhatoda*) and Indian privet (*Vitex negundo*) (each 200 g of leaves per L of water).	Neupane, 1999
Nematode in vegetable roots	Mustard meal reduced root knot nematode galling	(PPD, 2009).

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Biological method

There are several biological agents being known in Nepalese agriculture for insect pest management. Vertebrate bio control agents include birds (Robin, Pitta, Motmot, Kingfisher and Wood peckers), lizards, frogs, mangoose, snakes and bats. Similarly, invertebrate bio control agents include predators (spiders, ladybird beetles, praying mantids, dragonflies damselflies, syrphid flies, green lacewings), parasitoids (egg, larval and pupal parasitoids). The technique for mass rearing and stock maintenance of general predators like green lacewing (*Chrysoperla carnea*), ladybird beetle (*Coccinellidae septempunctata),* blue lady beetle *Curinus coeruleus*, larval parasitoid like *Cotesia plutellae, Orgilus lepidus* and egg parasitoid like *Trichogramma chilonis, Copidosoma koehleri,* has been developed by National Entomology Research Centre, NARC, Khumaltar which are effective against aphids, mealy bug, diamondback moth, potato tuber moth and Lepidopteran pest respectively. In-situ conservation of parasitoid *Aphelinus mali* is continuous at apple orchard in the centre. Similarly, the center has worked on entomopathogens such as Nuclear Polyhedrosis Virus of *Helicoverpa*, Nuclear Polyhedrosis Virus of *Plusia*, Granulo Virus of potato tuber moth, *Metarhizium anisopliae*, *Beauvaria bassiana*. The culture of fungus *Trichoderma viridae*, *Trichoderma harzinaum*, and bacteria *Pseudomonas* spp. are maintained in National Plant Pathology Research Centre NARC, Khumaltar. *Trichoderma viridae* and *Trichoderma harzinaum* suppress the soil inhabiting pathogenic fungi and this beneficial microorganism is gaining popularity in Nepal (Rijal and Shrestha, 2003). There are potential local strains of bacteria and fungi which have shown better results to suppress the soil inhabiting pathogenic fungi (seedling root rot by *Rhizoctonia solani*) and bacteria (PPD, 2015).

Until year 2020/21 one hundred seventy-one formulation (Fs) of bio pesticides with different trade name were registered. Among them, *Bacillus subtilis* in 4 Fs, *Bacillus thuringiensis* (Bt) in 5 Fs, *Nuclear Polyhedrosis Virus* (NPV) in 4 Fs, *Metarhizium anisopliae* in 10 Fs, *Beauveria bassiana* in 14 Fs, *Paecilomyces lilacinus* in 3 F, *Pseudomonas fluroscense* in 22 Fs, *Trichoderma harzianum* in 6 Fs, *Trichoderma viride* in 28 Fs, *Verticillium chlamydosporium* in 3 Fs, *Verticillum lecani* in 8 Fs are commercially available in Nepalese market (PQPMC, 2021). But they are comparatively expensive and beyond the reach of common farmers. Some research findings related to use of biological control agents are listed in Table 4.

Table 4. Research findings on use of biological control agents in organic pest management

Insect pests	Research findings	References
Eggplant fruit and shoot borer (EFSB), *Leucinodes orbonalis Guenee*	Release *Trichogramma chilonis* in the crop field @ 250,000 parasitized eggs per ha (@ 50, 000/release5 times at weekly intervals, starting from flowering. Spray *Bacillus thuringiensis* (Kurtsaki) (*Bt*) based formulations such as DIPEL @ 3 g per litrer water in the evening hours at 10 days intervals.	Paneru & Giri, 2011 Paneru & Bhurtyl, 2004
Potato tuber moth, *Pthorimaea operculella Zeller* on tubers and plants	Admix *Po*GV formulation obtained from wet dilution method (*Po*GV suspension diluted with water first and mixed with talcum) @ 5 g/kg of potato tubers.	Aryal, 2011
Aphids, *L.erysimiB.brassicae, M. Persicae*	Conserve/release predatory insects such as lady beetles [2- spotted (*Adalia bipunctata*), 7-spotted (*Coccinella septempunctata)],*Curinus coeruleus* beetle and their larvae, green lacewing larvae (*Chrysoperla carnea*) and	Neupane, 2000, E.D. 2002

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	syrphid larvae.	
Stem borers complex, *Chilo supressalis, Scirpophaga incertulas* and *S. innotata* on rice	Spray *Bacillus thuringiensis* (Kurtsaki)(*Bt*.) based formulations such as DIPEL or BIOLEP @ 3 g per liter water during evening hours, repeat application at 10 days interval.	NARC, 1999
	Release *Trichogramma chilonis (*Ishii)for 6 times @ 50,000 - 100,000 parasitized eggs per ha per week soon after appearance of moths in the crop field.	NARC, 1999
Tomato fruit borer, *Helicoverpa armigera Hubner* on Tomatoes	Mass rearing technology for *Trichogrammachilonis(*Ishii)along with its culture has been developed and maintained by NARC, Entomology Division, Khumaltar, Lalitpur, Nepal.	Paneru & Ghimire, 2011
	Spray crop with HaNPV at 250 LE + 1% jaggery along with sticker (0.5 ml BeepolperL) in the evening hours when the larvae are young or @ 1.5 ml of 250 LE ($5x10^{11}$ POBs) / litre water plus 0.01% fabric whitener (as UV retardant) plus 0.5 % molasses/jaggery in the evening hours in flowering to crop maturity stage.	Paneru & Bhurtyl, 2004 Paneru & Bhurtyl, 2004
	Spray *Bacillus thuringiensis*(Kurtsaki) based formulation like, DIPEL @ 3 g per liter water in the evening hours at 10 days interval.	
Tobacco Caterpillar, *Spodoptera litura* Fabricius	Spray Spodoptera NPV 250 LE/ha + 1% jaggery along with sticker (0.5 ml Beepol /litre) in the evening hours. Release egg parasitoids *Trichogramma chilonis*(Ishii) in crop fieldsfor 6 weeks @ 50,000 eggs per ha per week soon after appearance of moths in the crop.	Paneru and Giri, 2011, NARC, 1999

Others

There are many other effective substances used in biological control of pest. Some of such substance is wood ash, agri lime, cattle urine, animal milk, fine soil, vegetable oil, baking soda etc. The farmers used to mix wood ash with grains against weevils (Paudyal, 2003). The drenching of wood ash and castor oil mixture (3:1 ratio) 2-3 times in the nursery bed soil at 10 days interval is effective against damping off disease (Paneru and Khadgi, 2007). Dusting wood ashes on plant foliage in the morning hours control aphids (NARC, 1999). Similarly, incorporation of 2 tea spoonful agri-lime in soil around tomato seedlings is effective against damping off diseases. Many farmers and researchers claim good control of aphids, mealy bugs, leaf feeding beetles and plant diseases by the use of water diluted cattle urine and use animal milk against cucumber mosaic virus and other fungal diseases (Paudyal, 2003).

Prospects

Nepal is rich in biodiversity. One of the principles of organic plant production is to maintain tree lines and natural areas within the farm to provide favorable conditions (e.g. nesting sites, nectar, pollen, secondary host) for the natural enemies of pest and disease. Forty-five percent of land area in Nepal is occupied by natural forest (MOALD, 2021) indicating great potential of Organic farming. Bio-control agents (insect predators, parasitoids and pathogens) are abundantly available to suppress crop pests in Nepalese agri-ecosystem naturally and there is a great scope of enhancing biological control agents through inoculation and augmentation. The rich forest diversity possesses diverse range of plants having pesticidal properties;

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Neupane, 2003 has reported more than 324 plant species having pesticidal properties. Nepalese farmers are rich in traditional knowledge to protect standing crops and post-harvest agricultural products from pest attack which can be utilized or modified for organic production. Commercial formulations of bio-pesticides are available in Nepal from India and China including various other countries. There is also an ample scope of utilizing own biodiversity for production bio pesticides through research and innovation. There is abundance of entomopathogenic nematode in Nepal's soil which could be exploited for biological control programe (Khatri-Chetri, 2011a). *Steinernema lamjungense* n. sp. was isolated and described for the first time form soil of Nepal (Khatri-Chetri et al, 2011b whereas *Heterorhabditis indica*, *Steinernema abbasi*, *S. cholashanense*, *S. feltiae* and *S. siamkayai* were explored from soil sample from different part of the country (Khatri-Chetri et al, 2010). Biological control agents of recently invaded fall armyworm has already been explored where *Trichogramma chilonis* (larval parasitoid) *and Telenomus remus (*egg parasitoid*)* were isolated from Nepal (Elibariki et al.. 2020) and rearing method of these parasitoids has been already established (NERC, 2022). So there is lot of potential in pursuing research in biological control agent in Nepalese context for ensuring guaranteed organic agriculture. Furthermore, major area of hills and mountains are still free from chemical fertilizers and pesticides, and are termed as "by default organic production area". These areas need small effort in pest management compared to commercial area.

There is a growing demand for organic foods at domestic and international markets. Consumers' awareness is increasing on organic agriculture products in Nepal and worldwide. Trading organic products to its giant neighbors, the China in the north and India in the south opens the vast scope of organic farming. Considerable quantity of quality products can be made available to growing number of tourists and domestic consumers. The niche produce in some specific locations has the geographical advantages. The national policy is being formulated in favor of organic agriculture and the government is providing support for organic certification. Most of the Nepalese farmers are familiar with IPM approach in agriculture which can be utilized or modified for organic production. Organic plant protection practices are compatible to Nepalese farmers. Organic plant protection measures are ecofriendly, and safe to human, animals and other non-target organisms as compared to synthetic chemical pesticides.

Challenges

In Nepalese market, organic plant protection technologies and products are insufficient to tackle pest problems in organic agriculture. Nepalese farmers are not well familiar to biological control measures. The use of bio-control agents (either augmentation or habitat management) needs high skill precision and is tedious. They are effective in controlled production system but they are less effective in field condition. In Nepal, research focus on bio-pesticides is limited. Isolated practice of the organic plant protection measures by one or few farmers around the vicinity will not come out with significant results. Organic plant protection technology cannot prevent pest outbreaks. The use of organic plant protection technology will not make crops completely free of pest attack. So, there will be crop yield losses by pests. There are insufficient training materials with experts and farmers to use and promote organic plant protection measures. Lack of public awareness on long term hazardous effect of chemical pesticides on human health and environment among the policy makers, development activists and farmers' communities has become major challenge to promote organic plant protection measures. Private sectors are reluctant to mass production of bio-

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control agents, so the farmers would not find these agents regularly and easily. Storage of bio-pesticides (bio fungicides/bio insecticides) in the Agro Vets is of serious concerns i.e not properly stored in relation to the viability of the microorganisms present. Bio pesticides available in market do not show required colony forming unit or viability. Lack of organic inputs like seeds, bio-fertilizers and bio-pesticides.

WAY FORWARD

- Establish basic infrastructure for the exploration, mass production and release of promising bio-control agents (predators, parasitoids and microbial) against major crop pests, weeds and diseases.
- Explore and document indigenous knowledge (IK) of Nepalese farmers' communities for organic agriculture.
- Provide subsidy to organic pesticide and bio-pesticide production center.
- Encourage farmers' communities to grow pesticidal plants in the potential growing sites providing training, subsidy and insurance.
- Make aware of policy makers, development activists, general public and farmers' communities on the importance organic pesticides and bio-pesticides
- Arrange to register organic pesticide and bio-pesticide in an easier manner as compared to chemical pesticides. Formulation of organic farming friendly policy, law and by-laws.
- Incorporate organic pest management technique in the courses of agriculture education and research system in all school, college and universities level.
- Develop and disseminate a package of organic technologies to the farmers to tackle their pest problems in organic agriculture.
- Determine self-life, persistence, residues and active ingredients of botanical products having pest killing properties.
- Encourage IPM farmers for organic production. Many IPM techniques are useful to organic agriculture.

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S. Pandey and S. Aryal prepared the manuscript. K. P. Timsina and L.N. Aryal helped in revision of the manuscript.

Conflict of Interest

The authors of the paper declare that there is no conflict of interest for the publication of this manuscript.

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