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Comparative Advantage of Using Bio-pesticides in Indian Agro-ecosystems

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ABSTRACT

The use of unsustainable levels of plant protection chemicals and fertilizers has resulted in a steady decline in soil quality and crop productivity the world over. To combat this decline, agricultural practices must evolve to meet the growing global demand for food without irreversibly damaging the world's natural resources.Bio-pesticides have tremendous potential to bring sustainability to agriculture and environmental safety. This article is part of a larger study conducted in India by the authors at the Université de Montréal with the support of Mitacs and Earth Alive Clean Technologies. In this research, farmers, manufacturers or suppliers of biopesticides, and R&D scientists were interviewed, and their responses demonstrate the advantages of applying microbial biopesticides to field crops. Participants reported a15-30% increase in yields and crop production after the application of biopesticides, with better quality and quantity of fruits, grains, and tubers with a longer shelf life. Moreover, while the risk of crop loss is high (60-70%) with chemically grown crops, this risk is reduced to 33% on average when crops are grown using biopesticides. The risk of crop loss is thus considerably reduced by the use of biopesticides.Yet, despite their positive impact on the health of humans, soil,ecosystems, and friendly invertebrates,biopesticides face significant challenges and competition vis-à-vis synthetic pesticides for a variety of reasons. The development of biopesticides must overcome the problems of improper formulations, short shelf life, delayed action, and high market costs, as well as a variety of legal/registration issues.

KEYWORDS: *Biopesticides; Biologicals; Advantage; Ecological risks; Economic risks; Farmers' Preference*

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INTRODUCTION:

There are an estimated 67,000 different crop pest species - including plant pathogens, weeds, invertebrates and some vertebrate species - and together they cause an approximately 40% reduction in the world's crop yield (Oerke*et al.*, 1994). One way to increase food availability is to improve the management of these pests. However, the unsustainable application of plant protection chemicals has resulted in the steady decline of soil health and crop productivities the world over (Aktar, Senguptaand Chowdhury, 2009). To reverse this decline, agricultural practices must evolve to sustainably meet the growing global demand for food without irreversibly damaging the world's natural resources (especially soil). Simply put, increasing food yields cannot be achieved through unsustainable utilization of water, energy, chemicals, and land. Investing in sustainable agriculture is one of the most effective ways to simultaneously achieve the sustainable development goals (SDGs) related to poverty and hunger, nutrition and health, education, economic and social growth, peace and security, and the preservation of the world's environment (Earth Alive, 2017). Biopesticides hold the potential to increase farmers' current agricultural productivity, while at the same time contributing to the soil's ability to produce more in the future. Several countries such as Canada, Argentina, South Africa, Australia, USA and Brazil, among others, have embraced these technologies. The list of potential commercial products that promise increased yield for the farmer continues to grow (Simiyu *et al.*, 2013).

Although insect pests remain one of the major limiting factors in sustaining the productivity of various crops, the indiscriminate use of chemical pesticides negatively affects humans and their environment (Rani *et al*., 2013). Agriculture is one of the most important economic sectors within developing countries, and economic development in India is largely dependent upon the development of agriculture.

The scope of this study was confined to microbial products used for plant protection. According to scientists, biopesticides have minimal impact on non-target organisms (OECD 2009: 11). Possessing complex modes of action, they are not prone to resistance and help reduce the development of resistance when used in resistance management programs (Arjjumend and Koutouki, 2018). Biopesticides also hold significant benefits for growers, offering:

- Minimal impact on non-target organisms;

- Pest control, thereby enhancing crop quality and yields;
- Improved export opportunities, because most are exempt from minimum residue limits;
- Organically approved status that allows organic growers to control pests while maintaining their certified status.

Biopesticides are derived from organisms including plants, bacteria and other microbes, fungi, and nematodes (Copping, 2009; EPA, 2012). They are often important components of integrated pest management (IPM) programmes and have received a great deal of attention as substitutes to synthetic chemical plant protection products (PPPs). There are three broad categories of biopesticides: microbial biopesticides, botanical biopesticides, and semiochemicals. Microbial biopesticides are derived from fungi, bacteria, algae, viruses, nematodes and protozoa, and other compounds produced directly from these microbes such as metabolites (van Lenteren, 2012). The names of some microbial biopesticides are shown in Table 1. A detailed biotechnological account of biopesticides is described by Arjjumend and Koutouki (2018).

Table 1: List of some important microbial biopesticides

Common name	***Target insects***	***Reference***
Entomopathogenic viruses		
Corn earworm NPV (HezeSNPV)	*Helicoverpa zea*: corn earworm, tomato fruitworm, tobacco budworm, *Helioth virescens*	Rowley, Popham and Harrison (2011)
Cotton bollworm NPV (HearNPV)	*Helicoverpa armigera*, cotton bollworm, pod borer	Rowley, Popham and Harrison (2011); Hauxwell *et al*. (2010); Rabindra and Grzywacz (2010); Yang *et al*. (2012)
Diamond back moth GV	*Plutella xylostella*	Yang *et al*. (2012)
Velvetbean caterpillar, NPV (AngeMNPV)	*Anticarsia gemmatal*is	Moscardi *et al*. (2012); Panazzi (2013)
Alfalfa looper NPV (AucaMNPV)	Noctuidae	Yang *et al*. (2012)
Tea moth (BuzuNPV)	*Buzura suppressaria*	Yang *et al*. (2012)
Entomopathogenic bacteria		
Bacillus thuringiensis subspecies kurstakia	Lepidoptera	van Frankenhuyzen (2009); Jurat-Fuentes and Jackson (2012)
B. thuringiensis sub-species aizawaia	Lepidoptera	Mashtoly *et al*. (2011)
B. thuringiensis sub-species japonensis	Coleoptera: Scarabaeidae	Mashtoly *et al*. (2010)
Paenibacillus popilliae	Coleoptera: Scarabaeidae, *Popillia japonica*	Koppenhofer, Jackson and Klein (2012)
Entomopathogenic fungi		
Aschersonia aleyrodis	Hemiptera	Lacey *et al*. (2011); McCoy *et al*. (2009)
Beauveria brongniartii	Coleoptera (Scarabaeidae)	Townsend, Nelson and Jackson (2010)
Conidiobolus thromboides Acari	Hemiptera, Thysanoptera	Hajek, Papierok and Eilenberg (2012)
Lecanicillium longisporum	Hemiptera	Down *et al.* (2009); Kim, Goettel and Gillespie (2009)
Metarhizium anisopliae sensu lato	Coleoptera, Diptera, Hemiptera, Isoptera	Lacey *et al*. (2011); Jaronski and Jackson (2012)
Nomuraea rileyi	Lepidoptera	Thakre *et al*. (2011)

Source: Nawaz, Mabubu and Hua, 2016

The second category of biopesticides, botanical biopesticides, are derived from plants that have the ability to kill or sterilize insects, to control weeds, or to regulate plant growth. Worldwide, nearly 6000 plant species have been identified with insecticidal properties (Nawaz, Mabubu and Hua, 2016). In India, the application of botanical biopesticides is a very old tradition. Products derived from plants such as neem (Azadirachta indica), custard apple (Annona reticulata), tobacco (Nicotiana tabacum), and pyrethrum (Tanacetum cinerariifolium) have been used as insecticides (Koul, 2012). Farmers apply botanicals to protect crops and stored products from insect pests. Studies have shown that botanical biopesticides have ecologically benign characteristics, such as a volatile nature and low environmental risks as compared to synthetic pesticides (Nawaz, Mabubu and Hua, 2016). Indeed, the minimal residual activity of botanical biopesticides does not affect predation, parasitism, or pollination by insects (Xu, 2011). Table 2 lists some important botanical biopesticides.

Table 2: Some plant products used as biopesticides

Plant product used as biopesticide	***Target pests***	***Reference***
Limonene and Linalool	Fleas, aphids and mites, also kill fire ants, several types of flies, paper wasps and house crickets	
Neem	*A variety of sucking and chewing insects*	Rowley, Popham and Harrison (2011)
Pyrethrum / Pyrethrins	*Ants, aphids, roaches, fleas, flies, and ticks*	Rowley, Popham and Harrison (2011); Hauxwell *et al.* (2010); Rabindra and Grzywacz (2010); Yang *et al.* (2012)
Rotenone	*Leaf-feeding insects, such as aphids, certain beetles (asparagus beetle, bean leaf beetle, Colorado potato beetle, cucumber beetle, flea beetle, strawberry leaf beetle, and others) and caterpillars, as well as fleas and lice on animals*	Yang *et al*. (2012)
Ryania	*Caterpillars (European corn borer, corn earworm, and others) and thrips*	Moscardi *et al*. (2012); Panazzi (2013)
Sabadilla	Squash bugs, harlequin bugs, thrips, caterpillars, leaf hoppers, and stink bugs	Yang *et al*. (2012)

Source: Salma, Ratul and Jogen, 2011

The third broad category of biopesticides is semiochemicals which are chemical signals produced by one organism that cause behavioral changes in an individual of the same or a different species (Chandler *et al.*, 2011). Commonly used semiochemicals for crop protection are insect sex pheromones, some of which can now be synthesized and are used for lure-and-kill systems (El-Sayed *et al*., 2009) and mating disruption (Chandler *et al.*, 2011). Worldwide, mating disruption is used on over 660,000 hectares of land and has been particularly useful on orchard crops (Witzgall *et al.*, 2008). According to Nawaz, Mabubu and Hua (2016), about 1000 kinds of insect pheromones have been identified so far and more than 30 target species have been controlled successfully by sex pheromones. Other types of semiochemicals are deployed to attract insect pests and kill them (Witzgall, Kirsh and Cock, 2010; Dhaliwal *et al.*, 2012). For example, the application of compounds such as jasmonic acid to plants can induce the production of herbivore-induced plant volatiles (HIPVs). Sodium alginate is an example of an HIPV that triggers biological control by attracting natural enemy insects and aphids (Heuskin *et al.*, 2012; Gurr, Simpson and Wratten, 2012).

The global biopesticide market has been growing in the double digits. More than 200 products are currently sold in the US market, compared to only 60 comparable products in the EU. More than 225 microbial biopesticides are manufactured in 30 OECD countries (Hubbard *et al.*, 2014). Countries like Canada, USA and Mexico use about 45% of the biopesticides sold, while Asia lags behind with the use of only 5% of biopesticides sold the world over (Bailey, Boyetchko and Längle, 2010). In India, the uptake has been rather slow. Biopesticides have low single digit market share (Urs, 2015). Along with neem (*Azadirechta indica*) derived products, *Trichoderma* strains of antagonistic fungi and *Pseudomonas fluorescens* bacteria dominate the market. The existing producers of biopesticides in India have also been losing credibility among farmers, as their products prove to be ineffective against serious pathogenic outbreaks. The supply chain is also problematic, as minor changes in temperature, humidity, and exposure to the UV spectrum severely affects the performance of the biopesticides.

This article is part of a larger study conducted between September 2017 and February 2020 by the authors at the Faculty of Law at the Université de Montréal, with the support of Mitacs and Earth Alive Clean Technologies.It focuses on the advantages of using biopesticides vis-à-vis chemical pesticides. Three different groups of participants were surveyed about biopesticides between April 2018 and March 2019 using methods that included semi-structured interviews, structured interviews, informal discussions, and observation. Response groups included farmers who use biofertilizers ("user farmers") and those who do not ("non-user farmers"), along with manufacturers or suppliers of biofertilizers, and R&D scientists.Their responses were recorded, leading to the conclusion that microbial products (biologicals) are advantageous when applied in field crops. The agronomic advantage of biopesticides compared to conventional chemical pesticides is well-proven biologically and in economic terms. Farmers have also shown their preference for biopesticides over chemical pesticides and have expressed a greater willingness to adopt biopesticides for better crop yields.

MATERIALS AND METHODS

Research was conducted in India to understand the comparative advantages of using biopesticides. The methods used to collect data for this research include primary surveys, interviews of participant groups, and observations made in the field.These methodologies are described below.

Sampling and Sample Techniques

Three participant groups were chosen to conduct this study: Group 1 (G. 1) - R&D Scientists; Group 2 (G.2) - Manufacturers and Suppliers; and Group 3 (G.3) - User & Non-User Farmers of Biopesticides. Group1 comprised those involved in the research and development (R&D) of biopesticides, as well as scientists conducting research on microbial agents. This group was included for their knowledge of and experience with the microbiology and agrochemistry of microbial biopesticides. Group2 participants includedthe manufacturers and suppliers of agro-biologicals, who are direct stakeholders involved in the supply chain. Finally, Group3 participants were farmers/cultivators/growers, some of whom were using biopesticides on their crops. These farmers were direct stakeholders of the study on biopesticides.

Table 3 contains the total sample size of each of the participant groups. For Group1 participants (R&D scientists), the total sample size was 12. The Indian states where the Group 1 participants were located are also indicated. Similarly, eight manufacturers/suppliers of biopesticides (Group2 participants) were interviewed in the specified states. Finally, 36 farmers (Group3 participants) were also sampled and interviewed. The distribution of these farmers is highlighted in Table 4. All the proposed participants except those in Group3 were first contacted by telephone and/or email in order to make an appointment. Following this initial contact, the participants were visited inperson and interviewed.

Data was collected from each participant group using different sampling techniques and research methods (Table 3). The farmers in G 3 group were divided into two major distinct categories: non-users of biopesticides, and users of biopesticides. They were then randomly sampled (Table 3). The composition of the sampling of these farmers is illustrated in Table 4.

Table 3: Sampling Techniques and Research Methods

Participant Group	*Sample Size*	*Names of States*	*Sampling Method*	*Research Method*
G.1 R&D Scientists	12	Uttarakhand, West Bengal, Telangana, Punjab, Delhi	Expert, Snowball	Informal discussion;
Semi-structured interview	A variety of sucking and chewing insects	Rowley, Popham and Harrison (2011)		
G.2 Manufacturers and Suppliers	8	West Bengal, Punjab, Haryana	Snowball, Purposive	Semi-structured interview; Structured interview
G.3 User & Non-User Farmers of Biopesticides	36	Uttarakhand, Punjab, Himachal Pradesh, Uttar Pradesh	Stratified random	Semi-structured interview; Structured interview; Observation

Table 4: Composition of Group3 Participants (Farmers)

Category of Farmers	*Punjab*	*Uttar Pradesh*	*Uttarakhand*	*Himachal Pradesh*	*Total*
Non-Users of Biopesticides	3	3	3	3	12
Users of Biopesticides	6	6	6	6	24
Total	9	9	9	9	36

Methods of Data Collection

As indicated in Table 3, different data collection methods were used to gather data from participant groups. For instance, information from Group1 participants (scientists) was collected using informal discussions and semi-structured interviews based on the questions listed in Appendix 1. On the other hand, manufacturers/suppliers (Group2 participants) gave their responses in accordance with the questions as listed in Appendix 2. The data gathering methods used were semi-structured and structured interviews as indicated in Table 3. The farmer group (Group3 participants) were surveyed by employing structured interviews, semi-structured interviews and observation methods. The questions for non-users of biologicals are listed in Table 5, while the questions for users of biologicals are listed in Table 6.

Certificat d'approbation éthique (Ethical Approval Certificate) and Compliance

The Multi-Faculty Committee on Research Ethics (*Comité plurifacultaire d'éthique de la recherche - CPER)* of the Université de Montréal issued an Ethical Approval Certificate (no. CPER-17-114-P)to the study project. The conditions of the Ethics Certificate were fulfilled during the collection of field data from all threeparticipant groups. In compliance with the Ethical Certificate, aConsent Form was presented to each of the individual participants in either English or Hindi, depending on participant preference, and was signed by both the participant and field researcher. Before conducting the interview or discussion with the participant(s), each individual was informed ofthe objectives of the research through an Information Sheet containing participant expectations, the participantbenefits of sharing information, details concerning confidentiality, and participants' right to withdraw. Information collection occurred only once explanations concerning the research had been provided and the freely given consent of the participant was obtained.

RESULTS

A sampling of 12 farmers (three farmers in each of four states) who were not using biopesticides and their responses to several questions were recorded (Table 5). These questions chiefly concerned their perceptions of the disadvantages of using chemical pesticides and the impacts they observed on the agroecosystem, human health, and domestic animals. Likewise, 24 farmers (sixfarmers in each of fourstates) who were using biopesticides were interviewed and their answers were recorded (Table 6). The responses of farmers in the "user" and "non-user" groups are analyzed and compared in the following subsections.

1. Soil performance with the use ofchemical pesticides and biopesticides

Participants whouse chemical pesticidesexpressed their views on how chemical pesticides affect the soil, plants, ecosystem, human health and animalhealth (Table 5). They indicated that the soil, air and water are contaminated by the use of chemical pesticides (Table 5). In turn, the contaminated soil causes public health hazards, threats to livestock, and damage to plants. Severalparticipants statedthat the number of cancer patients is increasing year by year in the state of Punjab due to the excessive use of chemical pesticides (Table 5). The farmers also highlighted the way in which pesticides affect the soil, ecosystem and humans. They described that a proneness to many diseases is created through constant or excessive use of chemical pesticides (Table 5). The effect of chemical pesticides manifests as an imbalance in the agroecosystem. Two important observationswere highlighted by farmers in this regard: 1) that the friendly insects and wasps die after exposure to toxic pesticides; and 2) that 90% of pesticide residues remain in the soil and enter the human body via the food chain (Table 5).

By contrast, farmers who use biopesticides expressed their views on how the biopesticides benefit the soil, plants, ecosystem, and human and animalhealth (Table 6). They responded that biopesticides can kill pest fungi, nematodes, insects and other pathogens(Table 6). According to several of the farmers interviewed, microbialbiopesticides support the soil biology and build soil health (Table 6).These farmers also described the ways in which soil health is protected or preserved usingbiopesticides. They statedthat the microbes inbiopesticides act only on the target eggs or larva of insect pests, or in some cases eat the spores of harmful fungi (Table 6). Manufacturers and suppliers also indicated that biopesticides help worms survive better in soil, as the soilremains healthy, protected, clean, residue-free and non-poisonous. Userfarmers also notedthat biopesticides do not have chemicals that cause damage to soil biology, and are cheaper and environmentally safe (Table 6).

Farmers who use biopesticides further explained the ways in which biopesticides address crop protection issues and how plants are protected from insects, pests, fungi, nematodes, etc. (Table 6). According to these farmers, biopesticides disrupt the life cycle of insect pests, especially the larval or pupal stage) without affecting other (non-target) organisms and without harming beneficial insects and fungi (Table 6). Moreover, biopesticides leave no ecological footprint (Table 6).

Table 5: Responses of control farmers/growers (Non-users of biopesticides)

Questions	*Himachal Pradesh*	*Uttarakhand*	*Punjab*	*Uttar Pradesh*
1. Soil performance with inputs of chemicals				
1.1. Do you think that chemical pesticides affect the soil, plants, ecosystem, human health and veterinary health?	• Soil and water are polluted • Yes	• Air and water are polluted seriously • Not known • Contamination of soil	• Yes. Health of livestock, human and soil is badly affected. Number of cancer patients is increasing year by year. Plants unhealthy despite adequate inputs • Water and soil are poisoned severely	• Yes • Soil and water are contaminated heavily • Poisonous soil causes health hazards
1.2. In what way do pesticides affect the soil, ecosystem and humans?	• Proneness is created to an extent • Not known	• Not known	• Very serious impact on soil and ecosystem	• Water and soil heavily poisoned • Friendly insects and wasps are killed. • Imbalance in agro-ecosystem • 90% of residues remain in soil and find way to human body via food chain
2. Investment & economic risks				
2.1. How much do/did you spend on buying chemical fertilizers and pesticides?	• INR 11000 pa • INR 3500 pa • INR 25000 pa	• INR 16000 • INR 15000 • INR 100000	• INR 20000 • INR 6000 per acre	• INR 1000 per acre • INR 7000 per acre • INR 30000
2.2. Can you calculate the economic or investment risks of crop cultivation under chemicals if the crop fails due to nutrients' deficit, disease, pests, nematodes, insects, etc.?	• Total loss	• 70% loss • 50-60% loss	• Loss of INR 2-2.5 x 10^5 • Loss of INR 1.25 x 10^5 • Paddy loss of INR 2-2.5 x 10^5 • Wheat loss of INR 1.5 x 10^5	• 50% loss
3. Health and ecological risks				
3.1. What are the common health effects of chemical pesticides? Especially on children and women.	• Weakness, indigestion, memory loss	• Health effects may appear in long term • Not known • Growth of children is affected	• Cancer, memory loss, weakness and skin disorders • Weight loss, energy inefficiency	• It causes cancer • Immunity loss • Skin diseases
3.2. Can you explain the ecological effects of chemical pesticides?	• Water is polluted • Water and air are polluted • Water, air and soil are poisoned	• No known effect in hills • Weakness and other toxic effects	• Serious effects on soil and plants	• Pesticides destroy beneficial microbes and insects
4. Other qualitative information				
4.1. What is preferred pesticide?	• Challenger, Durmet, Nuran • Chloropyritos	• Durmet, Challenger		• Chloropyritos, cypormethane

4.2 Do you want to use biopesticides?	• No	• Yes	• Yes	• Yes
4.3. What drives you to use biopesticides in future?		• Chemicals are expensive • Pesticides unsafe and expensive	• Not used so far • Health safety and security • Environmentally safe	• No adverse effect on human health and soil • Biopesticides are safer and cheaper
4.4. Which company/brand of pesticide(s) did you use?		• Tata Chemicals, Sri Ram Chemicals		
5. Additional Questions				
5.1. Do you prefer locally made products or foreign products?	• Local	• Local • Both	• Both • Local	• Local • Both
5.2. Would you be willing to pay more for a foreign product than for a local product?	• No	• No • Yes	• Yes	• No • Yes
5.3. Scale 1-10: How willing are you to try a new/ innovative product?	• 3 • 6	• 5 • 5 • 7	• 7 • 8	• 3 • 9
5.4. Which (local or international) organic certification do you trust?	• Local; • Not known	• Local • Not known • Both	• Local • Not known	• Both

2. Health and ecological risks from chemical pesticides

Farmers who usechemical pesticides discussed the common health effects of chemical pesticides, especially on children and women (Table 5). They named certain common diseases that can be attributed to usage of chemical pesticides,such as: weakness, indigestion, memory loss, cancer, skin disorders, weight loss, energy inefficiency andweakened immune system. They also stated that pesticide residues affect the growth of children. The users of chemical pesticides also explained the ecological effects of chemical pesticides. They highlighted that water, soil and air are polluted, and that ecosystems are severely affected as pesticides destroy beneficial microbes and insects in the soil and agroecosystem (Table 5). While some farmers of Uttarakhand felt that there was no known effect of pesticides in the hills, other farmers statedthat water, air and soil are polluted and contributed to eutrophication of water bodies. The farmers using chemical pesticides also felt that public health is severely affected by these products.

The users of biopesticides also commented on the common health effects of chemical pesticides (Table 6). They listed some illnesses linked to the use ofchemical pesticides in agriculture, including reproductive disorders, hearing impairment, respiratory problems, cancer, asthma, memory loss, poisoning, skin diseases, eye irritation, disturbance of menstrual cycle, and neurological issues in children (Table 6).

All participant farmers compared chemical pesticides and biopesticides (Table 6),stating that biopesticides are safer compared to chemical pesticides. Moreover, with respect to the comparative ecological advantage of biopesticides, the participant farmers using biopesticides expressed that biopesticides do not pollute, poison or contaminate water, soil and air, and that they keep the environment clean and protect agroecosystems (Table 6). They clearly explained that biopesticides are safer and non-toxic,causing no ecological harm or killing of non-target insects. When these farmers were asked to comment on the biosafety aspects of biopesticides, they statedthat biosafety of these products isensured because they are non-toxicand environmentally safer (Table 6).

3. Comparative yield & characteristics of produce

During field studies, farmers providedfeedback concerningthe effect of biopesticides on qualitative changes in crop production (Table 6). To the question "how do you measure the (comparative) productivity of crops accruing after usage of biopesticide(s)?" (Table 6), the farmers responded that they observed an increase in crop yields. Onefarmer estimated a yield increase of 15% after the use of biopesticides. The qualitative aspects of crops, such as taste, colour, quantity, and shelf-life, may also change with the use of biopesticides. To assess these changes, farmers were asked "how is the farm produce (grains, fruits, tubers) different when biopesticide(s) used?" (Table 6). The participant farmers statedthat the tubers, grains and fruits had abetter taste, size, quality, production, shelf-life, and colour after the use of biopesticides. According to them, the biopesticides kill the pests and fungi, without doing ecological damage (Table 6).

Table 6: Responses of farmers/growers (Users of biopesticides)

Questions	*Himachal Pradesh*	*Uttarakhand*	*Punjab*	*Uttar Pradesh*
1. Soil performance with the use of biopesticides				
1.1 Do you think that biopesticides benefit the soil, plants, ecosystem, human health and veterinary health?	• Yes	• Microbes kill the fungi and nematodes and protect plants • It protects plants from enemy insects and pathogens • Yes	• Yes • No air and water pollution	• Yes • Microbes support the soil biology
1.2 In what way do biopesticides address the crop protection issues? How are plants protected from insects, pests, fungi, nematodes, etc.?	• It works well • No pesticide residue is left in soil. • No poison in food • Biopesticides disturb the life cycle of pests without affecting other organisms	• No ecological footprint	• Microbes of biopesticides do not harm the beneficial insects and fungi • Microbes disrupt larval stage of insects	• Microbes kill the harmful insects and pests • It kills pests and protects soil
1.3 In what way is soil health protected or preserved by using biopesticides?	• Microbes of the biopesticides act only on target eggs or larva of the insect pests, or eat away the spores of harmful fungi. No chemical to damage soil biology.	• Biopesticides are not harmful • Cheaper and safe	• Biopesticides help worms survive better in soil • Environment remains clean • No pesticide residue in soil	• Non-poisonous • Biopesticides • Soil remains healthy
2. Comparative yield & characteristics of produce				
2.1 How does the application of biopesticides improve the crop productivity?	• Better fruits and grains with extended shelf life • Biopesticides kill the pests and fungi	• It improves production	• Yes	• Ecology remains safer
2.2. How is the farm produce (grains, fruits, tubers) different when biopesticide(s) used? [taste, color, quantity, shelf-life, etc.]		• Better produce	• Marketing after aggregation of all crop produce	• Fruits and grains are better
3. Comparative investment & economic risks				
3.1 How much do/did you spend on buying chemical fertilizers and pesticides?	• INR 1500 • INR 7000 • INR 40000 • INR 12000 • INR 15000 • INR 4000	• INR 2500 • INR 3000 • INR 15000 • INR 15000 • INR 1000 • INR 2.5×10^5	• INR 200000 • INR 6000-9000 • INR 60000-85000 • INR 32000-40000 • INR 9000 • INR 100000	• INR 15000 • INR 9000 • INR 80000 • INR 15000 • INR 9000 • INR 18000-80000
3.2 How much do/did you spend on buying biofertilizers and biopesticides?	• INR 1600 • INR 5000 • INR 10000 • INR 4000 • INR 9000 • INR 2000	• INR 1500 • INR 1500 • INR 5000 • INR 0 • INR 50000	• INR 65000 • INR 1000-2000 • INR 5000-9000 • INR 8000-10000 • INR 3000 • INR 30000-40000	• INR 9000 • INR 6000 • INR 15000 • INR 9000 • INR 6000 • INR 9000-15000

3.3. Can you calculate the economic or investment risks of crop cultivation under chemicals if the crop fails due to nutrient deficits, disease, pests, nematodes, insects, etc.?	• 60% loss • 75-90% loss • INR 2.5 x 10^5 loss	• 45% loss • 60-90% • 50% • 60%		• 70% loss • 90% loss • 70% loss • 80% loss
3.4 What investment or economic risks are involved if the crops are grown using biologicals?	• 30% loss • 25-40% loss	• Loss reduces • Bearable loss • Less loss	• Risk not calculated •	• 35-40% loss • 40% loss
3.5 Comparison of risks between both situations	• Risks reduce considerably if biologicals are used	• Chemical farming has more losses	• Risks in chemicals are very high	• 40% difference
4. Comparative health and ecological risks				
4.1 What are the common health effects of chemical pesticides? Examples	• Not known • Reproductive disorders • Hearing impairment • Respiratory problems • Cancer • Children are affected more • Asthma • Memory loss	• Poisoning • Cancer • Skin diseases • Eye irritation	• Disturbance of menstrual cycle • Cancer • Memory loss • Female health problems • Children's brain affected	• Cancer • Skin problems
4.2 Do you think that biopesticides are safer compared to chemical pesticides?	• Yes • Chemical pesticides cause serious health hazards		• Ecology is protected	• Not a poison • Not harmful • Yes
4.3 What is comparative ecological advantage of biopesticides?	• Biopesticides are safer and non-poisonous	• It keeps agroecosystem safe	• Biopesticides do not kill non-target insects	• No harm to ecology • Safer to ecology
4.4 Canyou comment on biosafety aspects of biopesticides?	• Not known		• Biosafety is ensured by biopesticides	• Non-poisonous and safe •
5. Other qualitative information about farmers' preferences				
5.1 What is preferred pesticide?		• Durmet • Marshall • Metacid • Alanto	• Whatever available in market	
5.2 Is biopesticide preferred over chemical pesticide? Why?	• Yes		• No	• Pseudomonas • Trichoderma
5.3 Are chemical pesticides and biopesticide(s) used simultaneously?	• No		• Yes	

5.4 What are perceived or recorded advantages of using biopesticides?	• Ecologically safe	• Adoption of organic farming	• Environmentally safer	
5.5 What drives you to spend on biopesticides?	• Safe and cheaper		• Cheaper and safe	
5.6 Which company/ brand biopesticide(s) do you use or like to use?		• IPL Co. Ltd.	• Whatever available in local market	• Trichoderma
6. Additional Questions				
6.1 Do you prefer locally made products or foreign products (biofertilizers or biopesticides)?	• Both • Local • It depends on CFU count	• Local	• Both • Local	• Both
6.2 Would you be willing to pay more for a foreign product than for a local product?	• Yes • No • If found better	• Yes • No	• Yes • No	• Yes
6.3 Scale 1-10: How willing are you to try a new/innovative product?	• 8 • 6 • 10 • 8 • 9 • 8	• 4 • 4 • 7 • 9 • 7 • 9	• 9 • 7 • 7 • 6 • 6 • 7	• 8 • 9 • 9 • 8 • 9 • 9
6.4 Which (local or international) organic certification do you trust?	• Both • International	• Local • Both		
6.5 What soil amendment products do you currently use?	• Rhizobium • Vermicompost, Krishma • Waste decomposer • Azotobacter	• Rhizobium • Vermicompost		
6.6 Are you experiencing problems with impoverished soil?	• No	• Yes • No	• No	• No

4. Comparative investment and economic risks

The users of chemical pesticides were asked how much money they spend on purchasing chemical fertilizers and pesticides (Table 5). Ten farmers gave arough estimate of their expenditure which averaged 13,450 Indian rupees (INR) per annum per farmer. By contrast, 23 of the 24 surveyed farmers who use biopesticides, stated that their expenditure on chemical fertilizers and pesticides ranged from INR 1000 to INR 250,000 per annum, with an average of INR 43,370 per annum (Table 6). Ofthose using biopesticides, 22 farmers stated thattheir expenditure on biofertilizers and biopesticides was an average of INR 12,141 per annum. This amount is far less than the tenfarmers' average spending of INR 13,450and 23 farmers' average spending of INR 43,370 per annum (Table 6) on buying chemical fertilizers and pesticides.

Surveyed farmers using chemical pesticidesalso gave a rough calculation of the economic or investment risks of crop cultivation if the crop fails due to nutrient deficiency, disease, pests, nematodes, insects, etc. (Table 5). Several farmers assessed these risks as being between50% to 70% (average 60%) of their total investment, while other farmers expressed these losses or risks in terms of amounts ranging from INR 125,000 to INR 250,000 per hectare per annum (Table 5). By contrast, some of the farmers using biofertilizers and biopesticides stated that the loss due to chemicals ranged from 45% to 90% with anaverage of 68% (Table 6), while others estimated this loss to be around INR 250,000.

With respect to the investment or economic risks involved if the crops are grown using biologicals, those farmers using biofertilizers and biopesticides estimated that the risk was between 25% and 40%, and stated that they found this risk to bebearable (Table 6). Thus, while the risk of loss was quite high (60-70%) with chemically-grown crops, the risk of loss was reduced to an average of 33%with the use of biopesticides(Table 6).

5. Farmers' preferences for pesticides and biopesticides

The users of chemical pesticides were asked abouttheir preference of chemicalpesticides, as well as their potential preferences if biopesticideswereoffered to them (Table 5). Similarly, the users of biopesticides expressed their preferences (Table 6). Common pesticides used by both types of farmers include Challenger, Durmet, Nuran, Chloropyritos, Cypormethane, Marshall, Metacid and Alanto.

Users of chemical pesticides in Uttarakhand, Punjab and Uttar Pradesh reported that they would like to use biopesticides if they could get access to them. The farmers of Himachal Pradesh refused to consider the use of biopesticides. "What would drive you to use biopesticides in the future?" was anotherquestion put forward to farmers who use chemical pesticides (Table 5). These farmers respondedthat chemical pesticides are expensive, unsafe and toxic. On the contrary, biopesticides are safe with respect to human health, the environment, and soils, and are comparatively cheaper. The farmers of Himachal Pradesh did not respond to this question.

Nearly half of the participant farmers using biopesticides preferred biopesticides over chemical pesticides (Table 6), although they did not specify the reason forthis preference. However, they did report using*Pseudomonas* and *Trichoderma*in abundance. Many of the farmers have also used chemical pesticides and biopesticides simultaneously (Table 6). These participant farmers explained the perceived or recorded advantages of using biopesticides, highlighting that biopesticides are ecologically safe and are instrumental in adopting organic farming (Table 6). Because biopesticides are safer and cheaper, these farmers were motivated to spend money on buying biopesticides (Table 6). Participants reported the company International Panacea Ltd. as the main supplier of biopesticides.

Farmers were also asked about their preference for local or foreign pest control products. The farmers who use chemical pesticides showed a preference for using both local and foreign made biopesticides (Table 5). Similarly, farmers who use biopesticidesstatedtheir preference to both local and international products (Table 6). However, half of the farmers using chemical pesticides have shown no preference to pay more for a foreign product. With respect to their willingness to pay more for a foreign product than for a local product, there was a mixed response from farmers who use biopesticides. Half of these farmers indicated theirwillingness, while one farmer only indicated to pay more if the foreign product was better than the local product.

With respect to farmers' willingness to try a new/innovative biological product, 9 out of 12 farmers who use pesticides rated their willingness on a 10-point scale. The average willingness on this scale was5.89 out of 10 (Table 5). It is significant that nearly 60% of the farmers have a willingness to use biofertilizers or biopesticides in future. Likewise, all 24 farmers using biopesticides gave their willingness on a 10-point scale to try a new/innovative product (Table 6). Their average willingnesscomes to 7.6 (Table 6).

Certification and standards are key to the acceptance of, and preference for,biopesticides. Farmers using chemical pesticides and those using biopesticides bothstatedthat they trust local and international organic certification equally (Table 5).

DISCUSSIONS

1. Soil performance with the use ofchemical pesticides and biopesticides

Plantprotection chemicals (pesticides) can cause toxicity, poisoning and internal malfunction in the human body. Organophosphorus compounds and carbamates contain the enzyme cholinesterase, which destroys the nervous system of humans and animals. Moreover, pesticides kill beneficial microbes and insects, such as bees. Groundwater contamination, reservoir pollution and soil pollution are also caused by pesticides. Pesticides can persist in soil for 8-12 years and, with plowing, the pesticide residues pass into the air as a result of evaporation or dust. Poisonous soil causes public health hazards, threats to livestock, and damage to plants. Two important facts were highlighted by different participants: 1) that friendly insects and wasps die after exposure to toxic pesticides; and 2) that 90% of residues remain in soil and find a way to the human body via the food chain.

Bycontrast, biopesticides cause no harm to plants, soil orhuman health. Instead, antibiotic substances in biopesticides inhibit pathogens, and plant immunity is enhanced. Farmers explained that biopesticides are less harmful to the environment, and their action is directed exclusively at a certain group of pests and does not affect other insects, birds and mammals. For example, biopesticidal microbes feed on pathogenic fungi, preventing moldy fungi and root rot. Biopesticides also act as hyper-parasites and destroy the cell wall of pathogens. Biopesticides can form organic acids in the process of utilization of carbohydrates, as well as produce enzymes that contribute to the decomposition of phosphates. Microorganism-based biopesticides (bioagents: bacteria, viruses, fungi, etc.) usually target a narrow range of target organisms. Therefore, microbes kill precisely the targeted fungi, nematodes, enemy insects and pathogens. Accordingtothefarmers, biopesticides disturb/disrupt the life cycle (especially the larval or pupal stage) of insect pests without affecting other (non-target) organisms and without harming the beneficial insects and fungi.

2. Health and ecological risks from chemical pesticides

Common diseases caused by chemical pesticides include indigestion, memory loss, cancer, skin disorders, weight loss, energy inefficiency, immunity loss, hearing impairment, respiratory problems, asthma, poisoning, eye irritation, disturbance of menstrual cycles, neurological disorders in children, effects on the nervous system, effects on blood circulation, gastritis, ulcers, allergies, headaches, vomiting, rashes, autism in children, reproductive health problems (fertility, fetal development), and damage to the genetic, neurohumoral, immune, metabolic and other mechanisms of the fetus inpregnant women. Ecosystems are also affected, as pesticides destroy beneficial microbes and insects in the soil and agroecosystem. Water, air and soil are polluted, apart from heavy eutrophication of water bodies. Pesticides are also highly persistentin the environment. In relation to the ecological advantage of biopesticides, farmers indicated that biopesticides do not pollute, poison or contaminate water, soil or air, and that they keep the environment clean. Biopesticides are safer and non-toxic, causing no harm to the ecosystem or to humans. In addition, biopesticides do not kill non-target insects, and their biosafety is ensured because they act as antidotes and do not lead to chemicalization in the soil.

3. Comparative yield & characteristics of produce

Regarding the (comparative) productivity of crops, farmers observed a 15-30% increase in yields and crop production after using biopesticides. Using biopesticides also resulted in better fruits, grains, and tubers with a longer shelf life. As a result of biopesticides, risk of harvest failure was also reduced, and the health of plants improved. Not onlydoes germination increase because of biopesticides, but some bacteria also inhibit the growth of weeds,allowing crops to get more moisture and nutrition.

4. Comparative investment and economic risks

Expenditures per unit area of land on buying chemical pesticides/fertilizers and buying biofertilizers/biopesticides were compared. In India, the cost to usebiofertilizers and biopesticideswas roughly INR 12,141 per annum, compared to an average of INR 43,370 per annum to purchase chemical fertilizers and pesticides.Whilethe risk of the losses was quite high (60-70%) with chemically-grown crops, this risk dropped to an average of 33% if crops weregrown using biologicals. Therefore, the risks are considerably reduced if biologicals are used.

5. Farmers' preferences for pesticides and biopesticides

In India, common pesticides used by farmers include Challenger, Durmet, Nuran, Chloropyritos, Cypormethane, Marshall, Metacid and Alanto. The majority of farmers surveyed have used chemical pesticides and biopesticides simultaneously. Farmers used both local and foreign-made biopesticides. However, many participant farmers have shown no preference to pay more for a foreign product. Yet, the majority of farmers stated that they wouldpay more for foreign products if they wererelatively more effective and betterquality. In this context, the quality and effectiveness of products become very pertinent. To try a new or innovative product,chemical pesticide users rated their willingness as being 5.89 out of 10, while biopesticide users rated their willingness at 7.6 out of 10, on average. Thisshows that willingness among all types of farmers to try innovative products like biopesticides is quite high. As certification and standards are key to the acceptance and preference of biopesticides, farmers have equal trust in both Indian and foreign certifications and standards.

CONCLUSION

Biopesticides are expected to provide predictable performance, and must do so in an economically-viable manner if they are to become more widely accepted. Biopesticides have tremendous potential to contribute to more sustainable, environmentally friendlyagriculture.Moreover, the use of biopesticides was reported to increase yields by 15-30%, and to producebetter fruits, grains, and tubers with a longer shelf life.Farmers also felt that the use of biopesticides lowered their risks of economic losses significantly. These findings indicate that a large proportion of farmers prefer to use biopesticides if they are effective and high-quality products.

Yet biopesticides face significant challenges and competition vis-à-vis synthetic pesticides for a variety of reasons. In some cases, biopesticides are highly specific, targeting particular pests, while the market prefers products with broad-spectrum activity. In other cases, biopesticides are only effective at specific stages of a pest's lifecycle, further narrowing the biopesticide's usage and applicability. If not used in a specified dose, at a specified time, and on a specified crop, the biopesticide will be ineffective, and farmers may lack education or motivation, preferring broad-spectrum chemical pesticides instead. Hence, the development of biopesticides must overcome the problems of improper preparation or formulations, short shelf life, delayed action, high market costs, and legal/registration issues.

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APPENDIX 1. QUESTIONS FOR SCIENTISTS/ ACADEMICS

- **Scientific features of biologicals being manufactured**
  1. Composition or ingredients of biologicals
  2. Physico-chemical properties or characteristics of biologicals
  3. Fertility or epidemiological functions
  4. Efficacy or efficiency of biologicals
  5. Toxicological information
  6. Shelflife of the biological product
- **Characteristics of biologicals**
  1. How can biopesticides be distinguished from chemical pesticides?
  2. What are the general characteristics of biopesticides?
  3. How do biopesticides function when they are applied on plants, insects, herbs/weeds?
  4. Can you comment on the shelf life of biopesticides?
  5. What are ecological functions of biopesticides?
- **Comparative advantage of using biologicals**
  1. Are biopesticides economical compared to chemical pesticides?

2. Can you give any calculation of the costs of both?
3. How are biopesticides advantageous compared to chemical pesticides?
4. What are the ecological advantages of biopesticides?
5. Biosafety and hazardousness-related issues: which is better?
6. What are the advantages related to soil biology?
7. How will the use of biopesticides solve environmental problems?

Appendix 2. Manufacturers, suppliers, importers and traders of biopesticides

Questions	***Responses - India***
What kinds of biologicals in what quantities and with what effectiveness are being used by farmers?	
Categories of existing biopesticides manufactured or supplied/traded	• Pest control agents • Disease control agents • Biofungicides (*Trichoderma viride*, *Pseudomonas fluorescence*) • Biopesticides • Bioinsecticides (*Bacillus thuringiensis*) • Bionematicide (*Verticillium chlamydosporium*)
Any efficacy or efficiency tests/data of such biopesticides?	• Data not shared • Tests were done by CIB labs at the time of registration process
Any toxicological tests/data of these biopesticides?	• Most products specify names of target crops • No toxicological data shared
Biosafety issues associated with biopesticides and ways of tackling	• Biosafety tests were conducted by order of CIB at the time of registration

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