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 worldwide. To combat this decline, agricultural practices must evolve to meet the growing global demand for food without irreversibly damaging the world's natural resources. Biopesticides 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.

KEYWORDS: Biopesticides; Biologicals; Advantage; Ecological risks; Economic risks; Farmers’ Preference

INTRODUCTION:

There are 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, Sengupta, and 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 (AngeMNPy) | *Anticarsia gemmatalis*                                                      | Moscardi *et al.* (2012); Panazzi (2013)       |
| Alfalfa looper NPV (AucaMNPy)       | 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*                   | Hemiptera                                                                      | 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 | Rowley, Popham and Harrison (2011) |
| 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) |
| Rynia                             | 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 (Elsayed 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 (Azadirachta 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.

**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 Group 1 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 (Group 2 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 (Group 3 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 three participant groups. In compliance with the Ethical Certificate, an Consent 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 of the objectives of the research through an Information Sheet containing participant expectations, the participant benefits 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 (six farmers in each of four states) 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 of chemical pesticides and biopesticides

Participants whose chemical pesticides expressed their views on how chemical pesticides affect the soil, plants, ecosystem, human health and animal health (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. Several participants stated that 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 observations were 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 animal health (Table 6). They responded that biopesticides can kill pest fungi, nematodes, insects and other pathogens (Table 6). According to several of the farmers interviewed, microbial biopesticides support the soil biology and build soil health (Table 6). These farmers also described the ways in which soil health is protected or preserved using biopesticides. They stated that the microbes in biopesticides 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 soil remains healthy, protected, clean, residue-free and non-poisonous. User farmers also noted that 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                                 |                                                                            |
| 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 2000  
● 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                                                                                 | ● 70% loss                                                                  | ● Loss of INR 2-2.5 x 10⁵  
● Loss of INR 1.25 x 10⁵  
● Paddy loss of INR 2-2.5 x 10⁵  
● Wheat loss of INR 1.5 x 10⁵                                                       | ● 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                                                |                                                                            |
2. Health and ecological risks from chemical pesticides

Farmers who use chemical 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 and weakened 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 stated that 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 of chemical 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 stated that biopesticides of these products is ensured because they are non-toxic and environmentally safer (Table 6).

3. Comparative yield & characteristics of produce

During field studies, farmers provided feedback concerning the 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. One farmer 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 stated that the tubers, grains and fruits had a better 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 | 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 ecological footprint | Microbes of biopesticides do not harm the beneficial insects and fungi | Microbes kill the harmful insects and pests | Microbes disrupt larval stage of insects |
| 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 | Biopesticides help worms survive better 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 | 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 2500 | INR 20000 | INR 15000 | INR 6000-9000 | INR 60000-9000 | INR 15000 | INR 9000 |
|                                                | INR 7000 | INR 3000 | INR 6000-8500 | INR 9000 | INR 60000-85000 | INR 15000 | INR 9000 | INR 18000-8000 |
|                                                | INR 40000 | INR 15000 | INR 32000-40000 | INR 9000 | INR 15000 | INR 15000 | INR 9000 | INR 18000-8000 |
|                                                | INR 12000 | INR 10000 | INR 1000 | INR 10000 | INR 10000 | INR 18000-8000 |
|                                                | INR 15000 | INR 2.5 x 10^7 | INR 20000 | INR 9000 | INR 6000 | INR 18000-8000 |
|                                                | INR 4000 | INR 5000 | INR 6000 | INR 18000-80000 | INR 9000 | INR 6000 | INR 18000-80000 |
|                                                | INR 9000 | INR 1000-2000 | INR 9000 | INR 6000 | INR 18000-8000 |
|                                                | INR 2000 | INR 5000 | INR 9000 | INR 6000 | INR 18000-8000 |
| 3.2 How much do/did you spend on buying biofertilizers and biopesticides? | INR 1600 | INR 1500 | INR 65000 | INR 15000 | INR 9000 | INR 9000 |
|                                                | INR 5000 | INR 1500 | INR 6000 | INR 15000 | INR 9000 | INR 9000 |
|                                                | INR 10000 | INR 5000 | INR 1000 | INR 15000 | INR 9000 | INR 9000 |
|                                                | INR 4000 | INR 0 | INR 8000-1000 | INR 1000 | INR 9000 | INR 9000 |
|                                                | INR 9000 | INR 50000 | INR 3000 | INR 9000 | INR 9000 | INR 9000 |
|                                                | INR 2000 | INR 50000 | INR 3000-40000 | INR 9000 | INR 9000 | INR 9000 |
|                                                | INR 15000 | INR 9000 | INR 9000 | INR 9000 | INR 9000 | INR 9000 |
|                                                | INR 15000 | INR 6000 | INR 15000 | INR 9000 | INR 9000 | INR 9000 |
| 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 | 45% loss | 70% loss  
75-90% loss  
INR 2.5 x 10^5 loss | 50%  
60%  
60-90%  
90%  
70%  
80% |
|---|---|---|---|
| 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 Can you 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

6.2 Would you be willing to pay more for a foreign product than for a local product?
   - Yes
   - No
   - If found better

6.3 Scale 1-10: How willing are you to try a new/innovative product?
   - 1
   - 2
   - 3
   - 4
   - 5
   - 6
   - 7
   - 8
   - 9
   - 10

6.4 Which (local or international) organic certification do you trust?
   - Both
   - International

6.5 What soil amendment products do you currently use?
   - Rhizobium
   - Vermicompost, Krishna
   - Waste decomposer
   - Azotobacter

6.6 Are you experiencing problems with impoverished soil?
   - No
   - Yes

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 a rough 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). Of those using biopesticides, 22 farmers stated that their expenditure on biofertilizers and biopesticides was an average of INR 12,141 per annum. This amount is far less than the ten farmers’ average spending of INR 13,450 and 23 farmers’ average spending of INR 43,370 per annum (Table 6) on buying chemical fertilizers and pesticides.

Surveyed farmers using chemical pesticides also 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 between 50% 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 an average 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 be bearable (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 about their preference of chemical pesticides, as well as their potential preferences if biopesticides were offered 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 another question put forward to farmers who use chemical pesticides (Table 5). These farmers responded that 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 participants using biopesticides preferred biopesticides over chemical pesticides (Table 6), although they did not specify the reason for this preference. However, they did report using *Pseudomonas* and *Trichoderma* abundance. Many of the farmers have also used chemical pesticides and biopesticides simultaneously (Table 6). These participants 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 biopesticides stated their preference for 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 their willingness, 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 was 5.89 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 willingness comes 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 both stated that they trust local and international organic certification equally (Table 5).

**DISCUSSIONS**

1. Soil performance with the use of chemical pesticides and biopesticides

Plant protection 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, threatens 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.

By contrast, biopesticides cause no harm to plants, soil or human 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. According to the farmers,
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 in pregnant 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 persistent in 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 only does 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 use biofertilizers and biopesticides was roughly INR 12,141 per annum, compared to an average of INR 43,370 per annum to purchase chemical fertilizers and pesticides. While the risk of the losses was quite high (60-70%) with chemically-grown crops, this risk dropped to an average of 33% if crops were grown using biologics. Therefore, the risks are considerably reduced if biologics are used.

5. Farmers’ preferences for pesticides and biopesticides

In India, common pesticides used by farmers include Challenger, Durmet, Nuran, Chloropyritos, Cypermethane, 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 would pay more for foreign products if they were relatively more effective and better quality. 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. This shows 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 friendly agriculture. Moreover, the use of biopesticides was reported to increase yields by 15-30%, and to produce better 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 | • Pest control agents  
| Disease control agents | • Disease control agents  
| Biofungicides (Trichoderma viride, Pseudomonas fluorescense) | • Biofungicides (Trichoderma viride, Pseudomonas fluorescense)  
| Biostimulants | • Biostimulants  
| Biopesticides | • Biopesticides  
| Bioinsecticides (Bacillus thuringiensis) | • Bioinsecticides (Bacillus thuringiensis)  
| Bionematicide (Verticillium chlamydosporium) | • 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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