Biswas and Das
Bulletin of the National Research Centre (2024) 48:71
https://doi.org/10.1186/s42269-024-01226-x

Bulletin of the National Research Centre

REVIEW

Open Access

Organic farming to mitigate biotic stresses under climate change scenario

Saikat Biswas[1*] and Rupa Das[2]

Abstract

Background Climate change is inevitable owing from modern-day chemical agriculture, exerting detrimental impacts on sustainable crop production. Global agriculture is now facing serious threats from biotic stresses like weeds, pests, diseases, etc. These stresses not only hamper growth and production but also reduce crop quality.

Main body of the abstract Exclusive reliance on synthetic inputs to tackle biotic stresses has created resistance, resurgence, residues, etc., leading to environmental pollution. Although plants adopt defensive mechansims, such biotic stresses need to be addressed properly with various eco-friendly organic farming approaches. Suitable modification and adoption of various organic agronomic practices (manual, mechanical, cultural, and biological) such as soil solarization, crop rotation, intercropping, tillage, sowing time and method, nutrient, water and intercultural operations, organic formulations, selection of resistant/tolerant varieties, etc., can mitigate the negative impacts of biotic stresses to a high extent resulting in uplift in crop production as well as the quality of produce. Microorganisms not only alter soil health positively for high crop production but also alleviate biotic stresses through bio-stimulant properties. Various indigenous technical knowledge approaches show great promise to tackle biotic stresses further.

Short conclusion Adequate research, integration of multiple technologies, build-up of awareness, etc., are the keys for successful organic plant protection under changing climate scenario.

Keywords Agronomic management, Biotic stresses, Climate change, Crop growth, Organic farming practices, Production

Background

Various stresses in agroecosystems, both abiotic (temperature, water, sunlight, wind, salinity, nutrients, etc.) and biotic (bacteria, fungi, viruses, parasites, insects, weeds, etc.), have a significant impact on the quantity and quality of global agricultural production (Manghwar and Zaman 2024). This situation is exacerbated by shifting environmental factors such as climate variability, fluctuating temperature patterns, changing rainfall frequencies and intensities, and recurrent droughts, leading to a decline in biodiversity, increased incidences of pest, weed, disease infestations, etc. (Skendžić et al. 2021). Plants are vulnerable to several biotic stressors and unfavourable environmental conditions that can affect their morphological, biochemical, and molecular processes. 'Biotic stress' refers to the damage that plants suffer from living organisms such as pests, parasites, bacteria, fungi, nematodes, insects, and viruses (Nawaz et al. 2023). According to Yaman and Kumar (2021), biotic stress can lead to yield losses of 28.2% in wheat, 37.4% in rice, 31.2% in maize, 40.3% in potatoes, 26.3% in soybeans, and 28.8% in cotton. In order to prevent productivity losses, agriculture must be able to deal efficiently with biotic stressors. Plants create a variety of defence mechanisms to adapt to these conditions and survive (Zhang et al. 2024). They

*Correspondence:
Saikat Biswas
sbsaikatbiswas27@gmail.com
[1] Division of Agriculture, Faculty Centre of Agriculture, Rural and Tribal Development, Ramakrishna Mission Vivekananda Educational and Research Institute, Morabadi, Ranchi, Jharkhand 834008, India
[2] Faculty of Agriculture, Usha Martin University, Angara, Ranchi, Jharkhand 835103, India

recognize the environmental stressors, become activated, and then produce the necessary biological responses. However, in most cases, these defence mechanisms alone are insufficient and requires external strategies to cope up with stresses. Chemical fungicides, herbicides, and insecticides that effectively control diseases, weeds, and pests have shown to be harmful to the environment and to human health (Pathak et al. 2022). In addition to their accumulation in other environmental components, the use of chemicals also leads to the mortality of non-target organisms (residual impacts). For instance, herbicides are more successful in eradicating uncommon plant species than weed species (Gaba et al. 2016). To reduce the use of pesticides, safer alternatives must therefore be used.

It is worthy and high time to replace chemical-based agriculture with low-cost or no-cost, ecologically sustainable methods of organic farming, taking into account the growing concern about climate change (Biswas et al. 2024). Organic farming eschews the use of synthetic chemicals, instead relies primarily on manual, mechanical, cultural, and biological strategies to address biotic stresses, which is a particularly important in the context of climate change (Ghosh et al. 2021). Climate change has brought with it a major challenge that many minor biotic stresses are now becoming major ones and therefore, continuous modification, integration of existing strategies, etc., are extremely crucial to achieve effective crop protection (Biswas and Das 2023). Currently, there is an increasing demand for organically grown food worldwide. To maintain supply parity, organic crop cultivation requires the implementation of environmentally sustainable insect, disease, and weed management techniques. This review discusses some of these important ecologically safe organic farming strategies to mitigate biotic stresses in order to limit yield losses due to these stresses under climate change conditions.

Major biotic stresses affecting crop production

At any stage of their life cycles, including seedling establishment, plant development, or grain or fruit setting, crop plants are susceptible to attack from various biotic stresses highlighted hereunder.

Diseases

The invasion of pathogens by fungi, bacteria, and oomycetes exemplify biotic stressors. Worldwide, diseases caused by these pathogens stand as a principal driver of yield diminishment. Together with other aspects of global change, such as anthropogenic activities like air, water, and soil pollution, the introduction of alien species over long distances, urbanization, and drought, pathogens can be directly affected by climate change and thereby, influence plant diseases (Muluneh 2021). The negative consequences for the spread of viral diseases to new areas arise from global warming which increases the range of virus-transmitting insects, the globalization of agriculture, and international trade in seeds and seedlings (Jones 2021). Fungal diseases are ubiquitous in agriculture (Shukla et al. 2022). In addition to fungi, other microorganisms such as bacteria, virus, protozoa, etc., can damage seeds, cause root rots, and induce leaf spots, plant wilt, and other diseases in plants.

Insect pests

Insect pests, nematodes, etc., are significant biotic stresses in agriculture, and can cause considerable damage to crops, leading to declination in yields and economic losses (Nawaz et al. 2023). They also act as vectors of pathogens. The most important biotic stressor behind crop losses worldwide is insect pests. The amount of dry matter eaten by pests determines the direct losses, and contaminated processing products and damaged kernels cause the indirect losses (Berhe et al. 2022). Insect pests are highly adaptable in intentionally modified environments where crops are selected for their growth, productivity, and nutritional value and arranged in limited areas (Jankielsohn 2018). Insect pest management is critical for ensuring food security and the sustainability of agricultural systems.

Weeds

Indeed, weeds are considered as major biotic stresses in agriculture, as they compete with crops for important resources such as nutrients, water, and sunlight (Monteiro and Santos 2022). Monocropping exacerbates weed proliferation and often serves as a breeding ground for crop pests and pathogens (Kumar et al. 2021). Their seeds spread via air, water, birds, insects, human beings, livestock manures, agricultural equipments, etc. Climate change leads to significant losses in crop productivity, including weed flora shift, weed invasion into new areas, weed resistance to chemical herbicides, persistence of weed seed banks, etc. (Anwar et al. 2021). Weed control is, therefore, crucial for maintaining crop health and maximizing yields.

Organic ways to mitigate biotic stresses

The use of numerous technologies, such as mulching, multiple crops, flowering and nectar plants, trap crops, and cover crops, can effectively control many biotic stresses (Jeer et al. 2021). Careful and continuous monitoring of pest and disease infestations at critical stages of a crop's growth is key to efficient management. The farmer can achieve this by conducting regular zigzag field observations. There are many ways to combat biotic stresses (Fig. 1).

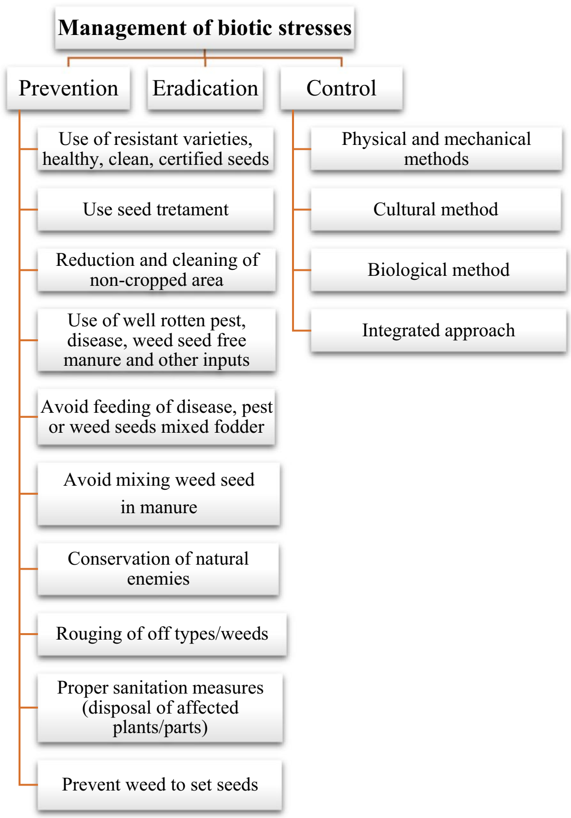

Fig. 1 Biotic stress management options

Physical and mechanical methods include the use of traps, baits, manual, and mechanical options to control the biotic stresses. For instances, manual collection of insects and larva, uprooting plants and destroying diseased parts, clipping off of the pest and disease infested leaves, hand weeding, hand hoeing, wheel hoeing, spudding, digging, chaining, flaming/burning weeds, soil solarisation, etc., all play a role in reducing biotic stresses (Rana and Rana 2019).

Cultural control is about modifying the environment, improving the health of host, or modifying the pest's behaviour to mitigate or prevent infestation. Crop rotation, crop and variety selection, sowing time, spacing, seed rate, time of harvesting, irrigation and nutrient management, tillage, mulching, intercropping, stale-seedbeds, summer fallow, and the use of trap crops all contribute to reducing populations of weeds, pathogens, insects, mites, and other pests in agricultural crops (Shekhar et al. 2024). It can be important to plan and select practices in advance, as certain cultural practices are preventive rather than curative (El-Shafie 2019).

Biological control includes the use of living organisms (bioagents such as predators and microorganisms) as well as plant products which can be successfully used against biotic stresses (He et al. 2021). It is important to emphasize that a single strategy is insufficient in most cases. A combination of mechanical, cultural, biological, and physical methods may be required to successfully reduce biotic stresses (Angon et al. 2023). Some common approaches to mitigate biotic stresses in organic agriculture are described below.

Soil solarization

Soil solarization is an effective ecological method to control weeds, soil, or seed-borne insect pest issues by covering the soil with a transparent polythene film. In a study conducted by Wada et al. (2024), soil solarization reduced the weed emergence by 67–96%. The radiant heat generated by solar radiation under a polyethylene film effectively kills insect and nematode pests at temperatures of 45–50 °C, penetrating to a depth of 5–6 cm within the soil. For effective crop yield and long-term pest control, it can be used in conjunction with other techniques such as mulching and organic amendments. Numerous plant-parasitic nematodes (PPN) are successfully controlled, including the root-knot nematode (*Meloidogyne* spp.) (Abolusoro et al. 2020), spiral nematodes (*Helicotylenchus* spp.) (Abd-Elgawad 2020), reniform nematodes (*Rotylenchulus reniformis*) (Shi et al. 2023), cyst nematodes (*Heterodera* spp. and *Globodera* spp.) (Mokrini et al. 2017), etc. Soil solarization effectively controls the major parasitic fungi and diseases such as damping off, root rot, stem rot, fruit rot, wilt, and blight caused by *Pythium* spp., *Phytophthora* spp., *Fusarium* spp., *Sclerotia rolfsii*, *Rhizoctonia solani*, *Sclerotinia sclerotiorum*, and *Verticillium* spp. It also successfully controls a variety of bacterial and fungal pathogens in soil, including *Agrobacterium tumefaciens, Macrophomina* spp., *Phytophthora* spp., *Verticillium* spp., *Rhizoctonia* spp., and *Pythium* spp. (Gill et al. 2017). Dwibedi and Dwibedi (2020) and Omotayo and Eegunranti (2023) observed that soil solarization effectively suppressed *Fusarium* wilt in guava and *Ralstonia* wilt in tomato, respectively. The fundamental process of soil solarization involves the use of plastic mulch to effectively trap solar radiation, increase the temperature of the soil surface, and destroy unfavourable soil microbes. Although it has no discernible effect on other soil chemical parameters, soil solarization lowers the pH, microbial respiration, microbial biomass, and concentrations of potassium (K), sodium (Na), boron (B), and zinc (Zn) in the soil. The heat generated by soil solarization plays an important role in reducing the population of microbes which cause crop wilts (Yuliar et al. 2015). The effectiveness of soil solarization in controlling weeds, nematodes, and black root rot in strawberries has already been demonstrated by Abd-Elgawad et al. (2019).

Crop rotation

Another environmentally friendly agronomic technique for coping with many biotic stresses in the soil ecosystem is sequential cropping or crop rotation. For a plant to thrive, living organisms must interact with their environment. Monocultures pose a greater threat to a plant's health, while on-farm crop rotation promotes a balanced relationship among various plants, pests, and predators. The basic principle of sequential cropping is the rotation of non-host plants to counter certain biotic stresses. Crop rotation influences the microclimate, necessary for many weeds to germinate and develop (de la Fuente et al. 2021). As a result, most weeds associated with crops disappear on their own. Since biotic stressors are usually specific to a single crop, an appropriate cropping system can be crucial to suppress them. In one study, a diversified crop rotation led to coping with biotic stresses and increased spring wheat production by up to 30% compared to monoculture (Jalli et al. 2021). Similarly, Volsi et al. (2022) confirmed the effectiveness of crop rotation in coping with biotic stresses, as they achieved high system productivity in a maize–soybean rotation through species diversification. Some instances of management of biotic stresses through crop rotation are shown in Table 1.

Table 1 Management of biotic stresses through crop rotation

Insects	Crop	Diseases	Crop	Nematodes	Crop	References
Hypera postica	Lucerne	Bacterial blight	Wheat, and barley	*Meloidogyne incognita*	Castor, marigold, rapeseed, common vetch, and velvet bean	Reddy (2017a)
Diabrotica virgifera	Maize	Bacterial wilt	Lucerne	*Meloidogyne javanica*	Velvet bean marigold, rapeseed, and common vetch	Reddy (2017a)
Leptinotarsa decemlineata	Tomato, and potato	Bacterial wilt	Tobacco, brinjal, and potato	*Meloidogyne arenaria*	Castor, marigold, sesame, and common vetch	Reddy (2017a)
Meromyza saltatrix	Wheat	Black shank	Tobacco	*Meloidogyne hapla*	Marigold	Reddy (2017a)
Anasa tristis	Cucurbita sp.	*Ustilago maydis*	Maize	–	–	Reddy (2017a)
Mayetiola destructor	Wheat	–	–	*Verticillium dahliae*	*Solanum tuberosum and Dianthus annus*	Reddy (2017a)
–	–	Anthracnose, Bacterial wilt, Common leaf spot, Spring black stem, Stagonospora	Alfalfa, small grains, beans, corn, sorghum, and forage grasses	Northern root-knot nematode	Alfalfa, cotton, black eye cowpeas, and lima bean	Long et al. (2024)
Wheat midge	Spring wheat, turnip rape, barley, and pea	Leaf blotch	Spring wheat, turnip rape, barley, and pea	–	–	Jalli et al. (2021)
–	–	–	–	*Meloidogyne incognita*	Wheat and lupin	Rahman et al. (2007)
–	–	–	–	*Meloidogyne hapla*, *M. incognita*, *Pratylenchus coffeae*, and *P. penetrans*	Strawberry and corn	Chen and Tsay (2006)
Corn root worm	Maize and soybean	–	–	–	–	Derpsch et al. (2011)
Colorado potato beetle	Potato/tomato and rye/wheat/bean	–	–	–	–	Capinera (2002)
–	–	*Kernel smut, false smut*	Soybean, rice, and corn	–	–	Brooks (2011)
Wheat stem maggot	Wheat and legume crops	–	–	–	–	
–	–	–	–	*Rotylenchulus reniformis*	Maize and cotton	Bruns et al. (2007)
–	–	*Sclerotinia* stem rot	Rapeseed, wheat, and barley	–	–	Hamid (2011)

Crop diversification

Crop growth can be increased by crop diversification, increasing competitiveness and weed tolerance. Diversely planted and harvested crops can prevent or lessen the growth of weeds and the formation of weed seeds. Due to their distinctive characteristics, weeds flower at certain times of the year. The weed problem can be solved by modifying the crop, which prevents the weeds in question from spreading. Controlling weed infestations has an indirect effect on the regulation of pests and diseases, as these weeds often serve as hosts for pests and pathogens (Dentika et al. 2021).

Stale seedbed technique

The stale seedbed technique (also known as false seedbed preparation) is a suitable option for controlling problematic weeds in the field. According to a study by Benvenuti et al. (2021), the weed seed bank investigation (10–30 cm) revealed that no depletion of weed seeds was observed beyond 10 cm soil depth, suggesting that buried seeds were unaffected by tillage methods beyond 10 cm soil depth.

In contrast, the germination stimulus induced by soil aeration and the associated increase in oxygen availability after tillage significantly reduced the weed seed bank in the shallowest soil layer (0–10 cm). When limiting variables for seed germination, such as oxygen, light, and soil-seed contact are present in the case of weed seeds deposited on the soil surface, seedbed preparation triggers germination of a portion of the weed seed bank (Boyd et al. 2006). In the stale seedbed method of weed control, soil disturbance is minimized and the toxic effects of herbicides can be prevented by allowing the weed seeds that are just below the soil surface to grow before they are killed and thereby, sowing the crop. The idea behind the stale seedbed method is that weeds that germinate and become visible before the crop sowing are easier to control. Here, the seedbeds are prepared and the weeds are encouraged to germinate by irrigation or rainfall. Thereafter, weeds are manually or mechanically suppressed prior to crop cultivation. Before sowing, the removal of freshly germinated weeds by harrowing with a blade harrow is very effective. The first one to two flushes of weeds are removed by harrowing before planting or sowing the crop (Senthilkumar et al. 2019). This method as a part of integrated weed management is very effective in annual or seasonal weed control of major field crops, vegetable crops, etc. Nalayini et al. (2023) reported effective weed suppression in irrigated cotton by using legumes like *Vigna unguiculata* and *Crotalaria juncea* in the seedbed.

Growing resistant varieties/competitive crop cultivars

Breeding resistant varieties/competitive crops is of greater importance as it has been observed in many cases that biotic stresses are often accompanied by abiotic stresses due to climate change (Guzmán et al. 2022). In organic farming, effective plant breeding techniques to develop suitable (resistant/tolerant) crop varieties can be instrumental in reducing the impact of biotic stresses such as pests and diseases (Ui-Allah et al. 2023). In a study, Padmavathi and Padmaja (2022) referred to the antixenosis, antibiosis, and tolerance mechanisms of the crop in combating biotic stressors. All three rusts of wheat have shown to be resistant to the cultivar 'PBW 343'; the cultivar 'Rewena' is resistant to apple scab; and the cultivars 'HD-29', 'HD-30', and 'HP 1531' are resistant to Karnal bunt of wheat (Iquebal et al. 2021). Certain varieties are better adapted to the soil moisture, space, air, and light than weeds due to their weed tolerance and ability to suppress weeds. As a result, they develop faster, outcompete weeds, and yield a greater quantity of fruits and vegetables.

Seed treatment and preservation

Effective seed treatment plays an important role in the containment of soil and seed-borne pathogens and insects. According to Rajput et al. (2021), there are several diseases and pests that can be controlled by hot water or hot air treatment such as whip smut, grassy shoot and red rot of sugarcane (52 °C for 30 min), loose smut of wheat (52 °C for 10 min), and others. In addition, seed treatment with *Trichoderma* can mitigate rotting and other pathogens (Tao et al. 2015). The use of neem-based materials can also be effective. In natural farming, now-a-days, plant protection properties can also be demonstrated by treating seeds with *Beejamrit, Beej Sanjeevani,* etc. (Biswas 2020).

In organic farming, it is common practice to store the seeds for sowing in the next season/year. Proper preservation and storage of seeds can maintain the seed quality by warding off storage insects and diseases. Adequate hygiene, ventilation, disinfection, and regular monitoring are essential. Periodic drying of seeds can reduce moisture content and thereby reduce pathogens (Dadlani et al. 2023). Storing seeds in airtight containers prevents the moisture absorption from humid air. Revitalizing seeds with neem-based materials, red chili powder, biochar, and similar substances can maintain seed quality over longer periods and repel biotic stresses (Das and Biswas 2022). Appropriate rat control measures should also be taken during seed preservation.

Soil management through nutrition and amendments

In conventional agriculture, the excessive use of nitrogenous fertilizers leads to an infestation of various insect pests. The formation of host metabolites, which can either prevent or promote infections by various pathogens, is also impaired by high nitrogen levels. If the roots are over-fertilized, subsequent diseases can develop due to salt damage to the roots. For instance, in crops grown in nitrogen-rich soils, the severity of rice blast (*Magnaporthe grisea*) and scald (*Rhyncosporium oryzae*) tends to increase, whereas maize head smut (*Sporisorium reilianum*) tends to infest less (Ghosh et al. 2021). Phosphate fertilization can increase the incidence of cucumber mosaic virus in spinach but reduce the incidence of potato scab (*Streptomyces scabies*) (Ghosh et al. 2021). Adequate potassium levels prevent the development of many different types of parasites, such as nematodes, bacteria (such as *Corynebacterium nodusum* and *Xanthomonas* sp.), fungi (such as *Fusarium oxysporum* f.sp. *vasinfectum*), and viruses (Do and Gries 2021). Adequate levels of calcium lead to increased resilience of cell walls against facultative pathogens such as *Rhizoctonia, Sclerotium, Botrytis*, and *Fusarium*. However, calcium-rich soils are conducive to the growth of diseases such as black shank of tobacco (*Phytophthora nicotianae*) (Pandey 2023). It is widely acknowledged that silicon enhances the ability of plants to withstand various biotic and abiotic stressors. Bakhat et al. (2018) reported that the plants of poaceae family exhibit the greatest capacity for silicon storage, followed by the cucurbitaceae and some solanaceae species. A variety of biotic stressors, such as root rot of cucumber and tomato, cucumber powdery mildew and chilli anthracnose, brown plant hopper, white-backed plant hopper, brown stem borer, leaf folder, green leaf hopper, stem maggot, leaf spider mites, root-knot nematode, blast disease of rice, wheat, and sorghum green bug, corn leaf aphid, sugarcane stalk-borer, and tomato wilt, can be controlled with silicon nutrition (Jeer et al. 2018). The incorporation of organic manure is essential for enhancing soil fertility and promoting optimal physical, chemical, and biological properties. This, in turn, fortifies plants against pests, diseases, etc. By supplementing the soil with organic amendments like sawdust, straw, oil cake, etc., *Pythium, Phytophthora, Verticillium, Macrophomina, Phymatotrichum*, and *Aphanomyces* infections can be efficiently managed (Rosskopf et al. 2020). Additionally, the utilization of neem, karanj, mahua, and other cakes can provide some level of control over soil-borne diseases and pests.

In organic farming, application of manures serves as an essential method for supplying nutrients to crops. Very often, it is witnessed that these manures spread diseases, insect pests, and weeds as the manures contain disease-causing pathogens, insect pests (adult, larva, eggs, etc.), and viable weed seeds (Yatoo et al. 2021). Therefore, a preventive approach and quality control measures should be implemented before usage. To mitigate the risks associated with manure application, it is imperative to ensure the proper breakdown of raw materials, eliminate any materials that may harbour disease-causing pathogens, insects or weed seeds, and conduct routine monitoring. When nutrients are applied, weeds tend to absorb a significant portion of these nutrients, leading to an increase in weed density and dry biomass accumulation (Kousta et al. 2023). According to Stewart et al. (2018), incorporating manure into the soil or using it as a sub-dressing can effectively suppress the growth of problematic weeds such as spotted spurge (*Euphorbia maculate*) and giant crabgrass (*Digitaria sanguinalis*).

Summer/deep ploughing

Soil dwelling pests such as nematodes and insects are driven off the field through regular soil disturbances during the summer (Kumar et al. 2020). Deep ploughing, combined with crop rotation and the use of biocontrol agents, can effectively control dry root rot and chickpea collar rot (Singh et al. 2018). This practice not only exposes insect larvae, eggs, nematodes, and pathogens to the sun's heat, but also reduces the viability of weed seeds due to increased solar radiation. Additionally, deep ploughing disrupts already established weeds and prevents them from setting seeds. Both annual and perennial weeds can be eliminated through deep ploughing in the summer by heating up the soil (Sharma and Rayamajhi 2022).

Irrigation methods

It has been evident that continuous flooding can significantly reduce the weed infestation from crop field through inhibiting weed respiration and creating anaerobic situation (Kaspary et al. 2020; Choudhary and Bhambri 2013). Low land paddy cultivation is, thereby, less infested from weeds than upland and aerobic paddy field (Liu et al. 2019). Specifically, flooding has been found to be particularly effective against grasses and broadleaf weeds such as *Cynodon dactylon, Alternanthera* spp., *Phyllanthus* spp., *Eclipta* spp., and *Commelina* spp. Micro-irrigation is another method that can effectively inhibit weed growth by delivering water directly to the roots of crops (Kaur et al. 2020). Removing weeds from irrigation ditches is another way to prevent their proliferation.

Biological control

One effective and sustainable method for managing biotic stresses in agriculture is the use of biocontrol agents such as parasitoids, predators, insects, and microorganisms (Prajapati et al. 2020). Potential biocontrol agents for numerous plant diseases include *Trichoderma* sp., *Azospirillum lipoforum*, *Gliocladium* sp., *Psuedomonas fluorescens*, *Bacillus subtilis*, *Aspergillus niger*, *Azotobacter chroococcum*, etc. *Pseudomonas fluorescens* and *Trichoderma* spp. alone can stop 92% and 96% of infections, respectively, but a combination of the two can stop 97% of infections of *Ralstonia* spp. (Yendyo et al. 2017). Furthermore, El-Saadony et al. (2022) also highlighted the potential of plant growth promoting rhizobacteria as effective biocontrol agents against various fungal and bacterial diseases in crops. Organic farming, as opposed to conventional agriculture, is known for its greater arthropod fauna diversity and the preservation of natural enemies (El-Shafie 2019). In addition to biocontrol agents, there are numerous bioherbicides available for weed control, such as Collego, Devine, and Biomal, which are produced by microorganisms (Hasan et al. 2021). Most often, in addition to insects, weeds and other pests can be effectively suppressed by competing plants, smother crops, mites, fish, etc. (Patil et al. 2020). Some living materials used for plant protection in organic farming are shown in Table 2.

Biofumigation

Biofumigation is a cutting-edge agronomic technology that utilizes non-chemical methods to combat biotic stresses such as soil-borne diseases, weeds, and insect pests (Rahman et al. 2021; Hanschen and Winkelmann 2020). This process involves introducing live plants of specific species into the soil, where they are chopped down to release organic volatile compounds that can effectively limit or eliminate these biotic stresses (Midzi et al. 2022; Gfeller et al. 2019). As biofumigants, the cruciferae family plants (Indian mustard, cabbage, cauliflower, and radish) can be used. Further, sorghum, marigold, and neem are few non-brassicaceae species that can be employed as biofumigants (Dutta et al. 2019). For instance, in mustard, when myrosinase is present, it forms glucosinolates, which when degraded release isothiocyanates to kill PPN (Brennan et al. 2020).

Plant biostimulants

Plant biostimulants derived from plant raw materials such as neem, karanj, and seaweed extracts, seed oils, and biomasses are recognized as effective tools for controlling plant-parasitic nematodes (PPN) and enhancing crop productivity (D'Addabbo et al. 2019; Ali et al. 2021). A study conducted by Rizvi et al. (2015) demonstrated that plant biostimulants containing sesame seed oil, neem biomass or seed meals, and quillay water extract effectively reduced populations of root-knot nematodes in tomatoes under greenhouse and field conditions. Additionally, research by La Spada et al. (2021) showed that post-harvest green mould caused by *Penicillium digitatum* in oranges could be suppressed by seaweed *Ascophyllum nodosum* and extracts from sugarcane and alfalfa. Similar to this, Kanatas et al. (2022) found that biostimulants had a beneficial effect on the control of noxious weeds.

Conservation tillage

In a certain agricultural habitat, conservation tillage promotes biodiversity, leading to increase in natural enemies along with insect pests (Jasrotia et al. 2023). However, with time, insect pests' survival rate decreases. Minimal soil disturbance by conservation tillage usually encourages the activity of soil dwelling insect pests (Alyokhin et al. 2020). As opposed to conventional tillage, which

Table 2 Some materials used for plant protection in organic farming

Material	Purpose of use
Kieselgur (diatomaceous earth) from the hardshelled diatom protist (chrysophytes)	Used as insecticide
Naturally occurring aluminium silicate (kaolin)	As insect repellent against a wide range of insects at a rate of 50 kg/ha
Sheep fat (obtained from fatty sheep tissues by heat extraction and mixed with water to obtain an oily water emulsion)	A repellent by smell against vertebrate pests such as deer and other game animals
Quartz sand	Used as repellent against vertebrate pests
Spinosad from the soil bacterium *Saccharopolyspora spinosa*	Used as insecticide
Quassia from the plant *Quassia amara*	Used as insecticide
Pyrethroids (only deltamethrin or lambdacyhalothrin)	Used only in traps with attractants or pheromones
Pyrethrins from the leaves of *Chrysanthemum cinerariaefolium*	Used as insecticide
Pheromones	Fungi and bacteria
Laminarin (from Laminaria digitata) or kelp or brown algae seaweed	Fungi and bacteria
Plant oils	Small-bodied insects such as thrips, aphids, and whiteflies

offers food and shelter to the majority of the natural enemies, conservation tillage creates a more complicated habitat for a variety of arthropods (Lichtenberg et al. 2023). Jecobsen et al. (2022) noted an increase in soil dwelling arthropod predators as a result of mulching and reduced tillage in conservation agriculture (CA). These insects, which include predatory beetles, spiders, ants, wasps, and earwigs, are found in the micro- and meso-environment. Another benefit of no-till farming is the enhancement of microbial activity and efficient resource utilization (Chauke et al. 2022). A study by Li et al. (2020) demonstrated that maintaining stubble under no-tillage had a significant impact on soil microbial diversity by altering soil organic carbon and total nitrogen concentrations. The integration of no-till farming with crop diversity is crucial for ensuring the sustainability of global agriculture (FAO 2014).

Biopesticides

Biopesticides have emerged as a sustainable and environmentally friendly alternative to chemical pesticides, addressing concerns related to pathogen and pest resistance, the harmful effects of synthetic chemicals on human health, soil microorganisms, ecosystems, and the environment, as well as the increasing cost of traditional pesticides (Ayilara et al. 2023). Microorganisms, natural pyrethrins, rapeseed oil, and paraffin are most frequently employed as insecticides; copper compounds, sulphur, and microorganisms are most frequently used as fungicides (Dar et al. 2021). Organic agricultural standards allow the use of unregistered products such as nettle slurry, which is used to smother aphids on plants. This idea permits the use of foods like vinegar and sunflower oil as plant protection. Sunflower oil, whey, and lecithins are examples of fungicides; vinegar has bactericidal and fungicidal properties; and *Urtica* sp. has insecticidal and acaricidal properties (El-Shafie 2019). In organic farming, *Dashparni* is a plant-based compound that is now being widely utilized to control insect pests along with other formulations such as Neemastra, Agniastra, and Brahmastra (Kumari et al. 2022) (Table 3). Despite their potential benefits, biopesticides are currently underutilized due to limited farmer accessibility and a lack of authorized products, despite their ability to effectively control harmful diseases and pests (Mishra et al. 2020). Sincere efforts are required if they are to become widely accepted by the farmers.

Biochar

Biochar is a valuable soil amendment produced through the controlled pyrolysis of organic materials at high temperatures (Amalina et al. 2022). The feedstock, temperature, pyrolysis conditions, and time all affect the quality of the biochar (Ippolito et al. 2020). Yang et al. (2022) demonstrated that the addition of biochar to soil not only increased plant biomass by 44.05% but also significantly reduced disease severity by 47.46%. Among different feedstock, biochar derived from straw has shown the strongest disease suppression capabilities. A global meta-analysis conducted by Iacomino et al. (2022) revealed that biochar can effectively reduce various soil pathogens and pests (86% of fungus, 100% of oomycetes, 100% of viruses, 96% of bacteria, and 50% of nematodes). Most studies used sawdust and wood waste as feedstock, with a range of application rates from 1 to 3% and a pyrolysis temperature of 500–600 °C. In addition to the detoxification of chemical agents, biochar can inhibit soil pathogens through various mechanisms, including (1) nutrient provision and improved nutrient uptake, which foster plant growth and resilience against pathogenic soil microbes; (2) microbe stimulation that directly inhibits soil pathogens through parasitism, competition, or antibiosis; and (3) biochar associated organic compaction. Furthermore, biochar has shown to suppress weed populations, as demonstrated in a study by Salman et al. (2020) where significant reductions in weed populations were observed in maize fields following biochar application.

Habitat management

The primary objective of tillage is to alter the soil's physical and chemical composition to make it more conducive to crop growth. By disturbing the soil, tillage effectively buries weed seeds deep within it, preventing them from germinating (Travlos et al. 2020). Additionally, it enhances aeration and removes entrenched perennial weeds. Conventional tillage methods are effective in eradicating weed flora from fields, while also reducing the density of wild weeds that struggle to thrive in cultivated environments. Weeds that grow between crop rows have their root systems disrupted by intercultural tillage. Moreover, tillage can directly kill insects through physical contact, malnutrition, exposure to predators, and adverse weather conditions. Furthermore, one of the simplest manual or mechanical pest management methods is hand-picking insects or weeds. Pests can also be physically or mechanically disrupted using techniques including mowing, hoeing, blazing, tilling or cultivation, and washing (El-Shafie 2019). Row coverings, safety nets with different mesh sizes depending on the pest, and sticky paper collars that stop crawling insects from climbing tree trunks are just a few of the tools that can be used in organic farming to keep insect pests from getting to crops. High-pressure water sprays can be used to eliminate insect pests such as mites and aphids from plant surfaces. Before transplanting rice seedlings, it is

Table 3 Ingredients and quantities for various bio-pesticide preparation

Biopesticides	Ingredients	Quantities mixed	References
Fungicide-I	Butter milk (5 days fermented)	5 L	Babu (2013)
	Water	50 L	
Fungicide-II	Indian bred cow milk	5 L	Babu (2013)
	Black pepper powder	200 g	
	Water	200 L	
Insecticide-I	Neem seed or leaf powder	20 kg	Babu (2013)
	Water	200 L	
Insecticide-II	Indian bred cow dung	5 kg	Babu (2013)
	Indian bred cow urine	10 L	
	Neem leaves	10 kg	
	Water	200 L	
Insecticide-III	Neem leaves (soaked in cow urine for 10 days)	10 kg	Babu (2013)
	Tobacco powder (soaked in cow urine for 10 days)	3 kg	
	Garlic paste (soaked in cow urine for 10 days)	3 kg	
	Green chilli paste (soaked in cow urine for 10 days)	4 kg	
Agniastra	Indian bred cow urine	10 L	Palekar (2014)
	Tobacco leaf	1 kg	
	Garlic	500 g	
	Green chilli	500 g	
	Urine-soaked neem leaves and pulp (Crushing and boiling of the leaves for 20–25 min, followed by keeping the mixture for 48 h)	5 kg	
Bramhastra	Neem leaves	3 kg	Palekar (2014)
	Guava leaves	2 kg	
	Papaya leaves	2 kg	
	Custard apple leaves	2 kg	
	Pomegranate leaves	2 kg	
	White datura leaves	2 kg	
	Lantana camara leaves	2 kg	
	Indian bred cow urine (Crushing and boiling of the leaves for 20–25 min, followed by keeping the mixture for 48 h)	10 L	
Neemastra	Indian bred cow urine	5 L	Palekar (2014)
	Cow dung	5 kg	
	Neem leaves and pulp	5 kg	
Chilli-garlic extract	Indian bred cow urine	10 L	Roy (2022)
	Chilli	500 g	
	Garlic	500 g	
	Ipomoea leaves	1 kg	
	Neem leaves (Boiling of mixture till half of the volume, followed by cooling for 24–48 h and straining)	5 kg	

recommended to clip the leaf tips to remove stem borer egg masses (Adane 2023).

Utilizing cover crops or live mulches, such as annual or perennial plants grown before or after the main crop to cover the soil for a season or a year, can significantly enhance the diversity and abundance of natural enemies (Kahl et al. 2019). In a study, red clover (*Trifolium pratense* L.) was employed as a cover crop in cucumber to encourage the action of natural enemies and stop the spread of melon aphid and stripped cucumber beetle (Kumara et al. 2021). According to Fernando and Shrestha (2023), cover crops offer a viable alternative to tillage for weed management, particularly during the winter season when optimal cover crop establishment is feasible. Through allelopathic action, interspecific competition, and niche prevalence, cover crops effectively suppress weeds (Shan et al. 2023). By strategically placing dead or living things between crop rows to shield the exposed areas from sunlight, the likelihood of weed development and germination is reduced, thereby minimizing competition for essential resources. Mulch materials serve a similar purpose by lowering water evaporation and increasing soil moisture availability. Through the release of allelochemicals, mulch materials can impede the weed growth and development (Khamare et al. 2022). Furthermore, nectar-producing flower plants play a crucial role in providing additional sustenance, fostering development, and increasing activity among natural enemies. Numerous plants within the compositae family are particularly effective in attracting the diverse array of natural enemies, serving as valuable sources of supplementary food, and eventually, aiding in the suppression of insect pests.

Time, method, depth, and density of sowing/planting

Numerous cultural techniques, such as changing the sowing method, timing, depth, and spacing, can make a decisive contribution in mitigating or avoiding biotic stressors in agriculture. Every disease and pest has a peak time for infestation. The peak time of infection can be controlled by changing the sowing date. For example, the shoot fly (*Atherigona soccata*, *A. naqvii*) occurs less frequently and is less damaging when maize is sown early (Arshad et al. 2019). Aphid infestation in mustard is higher when sown later (Viradiya and Gangwar 2022). Smuts and seedling diseases caused by *Fusarium* sp. and *Rhizoctonia* sp. are more severe when seeds are sown deep (Kelly 2020). Similarly, if potato seedlings are planted too deep, *Rhizoctonia* can damage them more quickly (Potato News Today 2021). Sometimes, the incidence of disease can be reduced by dense stands, resulting in higher crop yields. Since fragmented ground cover in Africa attracts the aphid vector of groundnut rosette virus more than continuous ground cover, dense planting helps prevent the vector from landing (Ghosh et al. 2021). The direction in which seeds are sown in some row crops can also influence the development of certain diseases. A large number of seeds produces many more plants per unit area and reduces the space available for the establishment and growth of weeds. As a result, there is less weed growth in the fields. Increasing the seed rate in wheat from 75 to 125 kg/ha leads to a reduction in weed growth and an increase in crop yield by 20–26% (Khasraw et al. 2023). As some weed species only sprout and grow at certain times, and they can be easily controlled by adjusting the sowing window. In one study, earlier sowing of maize resulted in heavier infestations of *Chenopodium album*, *Abutilon theopharsti*, and *Fallopia convolvulus* than at the normal sowing time (Vidotto et al. 2016). *Phalaris minor* generally has a lower density in wheat sown earlier (in November), but a higher density in wheat sown later (in December), resulting in a lower seed yield (Singh et al. 2019). The configuration of crop rows can significantly impact weed infestation levels. Narrow rows tend to have fewer weeds due to increased competition for space, while wider rows often experience more severe weed infestations as there is more room and resources available. For example, a study by Choudhary et al. (2021) found that planting rice in narrow rows with a width of 15 cm resulted in reduced weed emergence and establishment, leading to lower dry weed biomass and increased grain productivity. However, it is important to note that closer spacing can also have drawbacks. Increased humidity in the microclimate created by closer rows can potentially lead to higher levels of pests and diseases, as highlighted by Singh et al. (2023).

Traps and trap crop

Various types of traps are utilized in organic farming to effectively control pests. For instances, light traps can capture armyworms, cutworms, stem borers, and other nocturnal insects (Akeme et al. 2021). Colour and water traps are employed to suppress adult thrips populations, while yellow sticky traps are effective in controlling white flies, aphids, and leaf-mining flies. Pheromone traps, fruit bagging, mechanical picking of eggs, adults, larva, etc., are also used to capture the insect pests (Thakur et al. 2021).

Growing a trap crop near or in the vicinity of the primary crop can attract or divert insect pests. Some of the trap crops act as attractants, enticing insect pests to lay their eggs there and lessening the pest burden on the primary crop. A classic example is planting marigold around the perimeter to attract *Helicoverpa armigera* (Kumar and Cheema 2020). To suppress the diamond back moth in crucifers, trap crops such as Indian mustard are planted in a 25:1 ratio (Reddy 2017b). Castor is grown as a border crop and groundnut as a trap crop along cotton borders to lessen the effects of tobacco cut worms. Cowpea is used in groundnut fields as a trap to control the red-hairy caterpillar. Cultivation of pearl millet or sorghum near cotton fields deters thrips and whiteflies. *Desmodium* is grown between maize to repel the stem borers (Erdei et al. 2024).

Indigenous technical knowledge (ITK) approaches

Indigenous technical knowledge (ITK) encompasses the collective wisdom and practices unique to a culture, derived from generations of experience in navigating life's challenges (Sow and Ranjan 2021). ITK is a practical body of knowledge rooted in a community that has developed it, been preserved, and been refined through many generations by close interaction, close observation, and experimentation with its environment. It is evident that diverse ITKs are employed to combat biotic stresses in various regions (Bolaji Umar et al. 2022). Some are highlighted in Table 4.

Intercropping

Intercropping, the practice of growing of two or more crops together in a same field with distinct row arrangements is a beneficial agro-technique which covers the vacant spaces remained between main crop rows and thus, suppresses weeds. Crops and weeds compete for nutrition, light, and space. Since there is plenty of room, it usually grows in between the two rows of crops. Weeds are unable to sprout and spread when intercrop takes over that area because intercrop competes with weeds for resources. Furthermore, it lowers the weed plant population by obstructing sunlight, which is one of the key elements for weed growth (Scavo and Mauromicale 2020). Research works have repeatedly demonstrated that intercropping is generally more successful than mono cropping systems in weed suppression. For example, when smother crops like forage legumes are interplanted with a primary crops such as cereals, the weed-suppression effect is particularly pronounced. When the main crop struggles to compete with weeds, intercropping with grain crops can be an effective weed-suppression tactic (Nath et al. 2024). According to a research by Omovbude et al. (2017), intercropping reduces weed density by 43.2–59.7% and effectively smothers weeds by 84.2%. Intercrops can comprise of plants that are hosts or non-hosts of a certain pest. Intercrops can include plants that either attract or repel pests, helping to reduce pest pressure on the main crop. Insect pests and nematodes that are drawn to the intercrop can be eliminated using alternative strategies, such as organic pesticides. Many intercrops also secret poisonous chemicals. Intercrops with allelopathic effects offer a powerful defence against weeds, nematode, insect pests and soil-borne diseases (Chadfield et al. 2022). For instances, various allelochemicals released by different crops viz. rice (tricin and momilactone B), sorghum (sorgoleone), sunflower (heliannuols), etc., effectively supress the weeds in crop fields (Khamare et al. 2022). Previous research by Blaise et al. (2020) reported that sun hemp as an intercrop suppressed 43% weed biomass through the release of allelochemicals like phenolics and terpenoids. Various allelopathic actions of intercrops against weeds reported in numerous studies worldwide are summarized in Table 5. Additionally, the root exudates of intercrops play a crucial role in preventing the germination of spores, inhibiting the growth of pathogen mycelium, and impeding the hatching of young nematodes. *Verticillium dahliae* (Fu et al. 2015) and *Cylindrocladium parasiticum* (Gao et al. 2014) are good examples to illustrate the mechanism and effectiveness of the allelopathic process. Intercrops from the asteraceae family are known to produce exudates (thiaphenes and thiarubrines) that inhibit the hatching of plant-parasitic nematodes (Zhu and Morel 2019). Similarly, *Solanum sisymbriifolium*, when grown as an intercrop, protects the primary crop from the potato cyst nematode (*Globodera* sp.), by producing compounds that prevent nematode eggs from hatching (Mhatre et al. 2021). A recent study by Jiaxing et al. (2021) reported that when wheat was grown in close proximity to faba beans, *Fusarium oxysporum* f. sp. *fabae* infections were dramatically reduced through wheat exudates containing tartaric and malic acids.

Biocontrol agents/biostimulants

Certain microbes, such as *Bacillus*, *Pseudomonas*, *Acinetobacter calcoaceticus*, *Azotobacter*, *Azospirillum*, *Mesorhizobium*, *Bradyrhizobium*, and *Burkholderia* species, serve as biostimulants by producing indoleacetic acid, facilitating nitrogen fixation, producing siderophore, dhurin, and degrading organic matter to enhance plant growth and combat diseases (Ansari et al. 2023). Few instances of microbial consortium to manage plant diseases in organic farming are shown in Fig. 2. Antagonistic microorganisms inhibit pathogens through various mechanisms, including antibiosis, siderophore production to compete for iron, colonization of sites, nutrient acquisition from seeds and roots, activation of plant resistance mechanisms, inactivation of pathogen germination factors found in seed or root exudates, and degradation of pathogenicity factors (Saeed et al. 2021). One effective method by which biocontrol agents (BCA) suppress diseases is through production of antibiotics (Lahlali et al. 2022). Iron plays a crucial role in numerous metabolic and cellular processes in most microbes, with Fe (II) typically being oxidized to Fe (III) in microbial habitats, forming stable complexes. Some organisms secrete siderophores having a strong propensity to sequester iron from the surrounding environment, when the concentration of iron is too low (10^{-6} M) to support the microbial growth. Several indicators suggest that siderophore production under iron-limiting conditions may be the reason for the antagonistic behaviour of certain strains of *Pseudomonas aeruginosa* and *Pseudomonas fluorescens* towards *Fusarium oxysporum* and *Rhizoctonia solani* which are known to cause damping off in various crops (Abo-Zaid et al. 2023). Currently, only a few genera, species, and strains of BCAs are registered for use against soil-borne pathogens such as *Coniothyrium minitans*, *Gliocladium catenulatum*, *Pseudomonas chlororaphis*, *Streptomyces griseovirides*, *Streptomyces lydicus*, *Trichoderma asperellum*, *T. atroviride*, and

Table 4 Various ITK approaches to control biotic stresses

ITK approach	Controls
Ploughing with neem tree made wooden plough or application of neem cake @ 50 kg/ha to soil	Nut grass
Green manuring with Dhaincha and Sunhemp	*Cyperus rotundus* and other weeds
Fallowing black soil for three years	*Cynododon dactylon*
Top dressing of cow dung ash @ 50–60 kg/ha	*Cuscuta* weed
Mixed cropping of sorghum and coriander	*Striga lutea*
Application of common salts for seed treatment of lucerne	*Cuscuta reflexa*
Sorghum or pearl millet is grown in four very close rows around the fields	Mites and aphids from crop field
Intercropping of cowpea with sorghum	Stem borer through repulsive smell
Neem kernels or neem cake or neem cake extract is applied drop by drop to the sorghum shoots	Shoot borer
Growing castor on the fields, covering the nursery with neem leaves, dusting the pits with ash before planting tree seedlings, application of 5% solution of common salt on the trees, and watering frequently	Termites
1 kg of cotton seeds is glued with fresh cow dung; 200 ml of neem oil is added	Mealy bugs
Neem oil application @ 15 L/ha in black gram	Powdery mildew
Application of charcoal or kitchen ash	Leaf miners, thrips, shoot borers, aphids, etc
Burning of wastes on soil for sterilization and generation of heat in dry seasons	Damping off disease
Spraying of onion or garlic juice on maize	Grasshoppers and other insects
100 L of water is mixed with 5 kg of cow dung, 5 L of cow urine, and 150 g of lime before being allowed to ferment for a month	Aphids and bacterial and viral infections
In paddy fields, kerosene oil mixed with water is poured, while plants are simultaneously agitated by a long rope to make insects to fall into water	Hoppers
Trap having bow-shaped design composed of bamboo, iron wire, and jute rope, with one end acting as a spring and the other end trapping the rat when it approaches to consume the bait	Rats
Pulling kerosene-coated rope over the standing paddy crop	Stem borer, rice hispa, and case worm
Branches of Germani bon (*Chromolaena odorata*) emit unpleasant smell	Rice hispa and case worm
Hanging dead frogs, crabs (*Carcinide*s sp.), jackfruit (*Artocarpus heterophyllus*), and outenga (*Dilenia indica*) in rice field directly or in muslin cloth	Gandhi bug
Bamboo perches are installed in rice field for predaceous birds to take rest	Bugs and other insects of rice field
Use of peel of a pomelo as it contains limonene, terpinene, etc.	Rice hispa
Leaf cutting is used on rice seedlings for the removal of egg masses	Stem borer
Broadcasting of 5–10 kg or 8 kg of wood ash or rice husk per acre together with 3–5 L of kerosene in the morning	Stem borer
Use of defective audio-visual tapes, films, reflective ribbons, polythene flaps in fields of maize, sunflower, rice, wheat, etc., in a zigzag pattern	Birds
Broadcasting of goat excrement during the tillering stage to emit foul odour	Rice hispa
Scattering of drum stick (*Moringa oleifera*) twigs and bark across their rice fields	Stem borer
Trimming of the rice field's border edges before the transplanting	Hibernating insects
Use of neem leaves, curry leaves, red chilli powder, biochar etc. for seed storage	Storage insects
A 6–12-inch-thick layer of rice husk is placed on top of the grains during storage	Rice moth
Use of banana leaf sticks in rice field	Gandhi bug
Spraying 0.2% neem-based extract made by combining 250 g of neem leaves and 250 g of cow dung in 10 L of water over tea bushes	Red spider mites
Application of a fermented solution made of 5 kg of cow dung, 5 L of cow urine, 150 gram lime, and 100 L of water in rice	Khaira disease, bacterial, and viral infections
Putting fresh cow dung close to the chilli plant's collar	Damping off and dieback
Use of a solution from overnight mixing of 2 kg of fresh papaya leaves in 3–4 L of water in rice	Brown spot disease
Spraying ash in rice field	Brown spot disease
Putting rice straw at the base of the plant, particularly during the fruiting stage of tomato and brinjal for keeping plant and fruit branches from coming into contact with the soil	Blight and fruit rot
Spraying liquid waste from tanned leather in chilli	Bunchy top disease
Spraying of fish cleaned water at the base of lemon trees to emit foul fish smell	Citrus trunk borer

Table 4 (continued)

ITK approach	Controls
Ripe banana or crushed sugarcane stock is put in the ground close to the main field of potato plantations to attract insects towards the sweet flavour	Red ants and mites
Burning of rice husk, twigs, and other materials in the pit in coconut and arecanut plantations	Termites
Growing tomato and chilli seedlings to a height of 3 to 4 feet in an artificial tray made of half split bamboo	Damping off
Spraying of boiled tobacco leaf extract on vegetables due to its alkalinity and nicotine content	Lepidopteran insects
Placing a dead frog at the foot of a coconut tree to attract the insects through foul smell	Rhinoceros beetle
Application of turmeric powder to the seed bed of vegetable crops such as tomato, cabbage, cauliflower, etc.	Red ant
Rubbing of vegetable seeds with a solution of kerosene and ash before planting	Red ant
Rice straws and chilli powder are regularly burnt and smoked at the fruiting period in vegetable crops	Fruit fly
Spraying of a solution made from mixing 1 L of cow urine, 500 g jaggery, and 2 L of water and keeping for 6 months for decomposition in an airtight container	All agricultural pests
Crushing of 5 kg of neem leaves, adding of 5 lit of cow urine, and 2 kg of cow manure to water. Stirring is done occasionally while letting it ferment for 24 h. The extract is then filtered, diluted in 100 lit of water, and sprayed over an acre	Mealy bugs and sucking pests
Adding 5 kg of vitex leaves in 10 L of water to soak and then the solution is boiled for 30 min and cooled. The solution is sieved using cloth. Then, extract of 2 kg aloe vera is added and further diluted in 50–60 L of water	Armyworm, hairy caterpillar, rice leaf folder, rice stem borer, semi-looper, and bacterial and fungal infections
Mixing of 3 kg of neem leaves, 2 kg each of custard apple, papaya, pomegranate, and guava leaves, along with 10 L of cow urine and boiling. After 24 h, extract is strained	Sucking pests, pod/fruit borers

(*Source:* Patel 2013; Saha and Dutta 2013; Roy et al. 2015; Shakrawar et al. 2018; Kalita and Hazarika 2019; Gohain et al. 2019)

Table 5 Weed suppression by some intercrops through allelopathic actions

Intercrop(s)	Main crop	Impact on weeds	References
Chickpea	Wheat	Suppressed *Chenopodium album, Melilotus indicus, Medicago* sp.*, Anagallis arvensis, Lepidium didymium*, etc	Banik et al. (2006)
Sorghum	Maize	Suppressed *Cyperus rotundus, Fallopia convolvulus, Trianthema portulacastrum*, etc	Khalil et al. (2010)
Sorghum	Cotton	Suppressed *Cyperus rotundus*	Iqbal et al. (2007)
Maize	Cassava	Suppressed *Setaria faberi, Cynodon dactylon, Amaranthus retroflexus*, etc	Olasantan et al. (1994)
Canola	Wheat	Suppressed *Phalaris minor, Rumex obtusifolius, Chenopodium album, Lepidium didymium*, etc	Naeem (2011)
Cowpea	Maize	Suppressed *Echinochloa colona, Portulaca oleracea, Dactyloctenium aegyptium*, etc	Saudy (2015)
Barley	Field pea	Suppressed *Chenopodium album, Sinapis arvensis*, etc	Corre-Hellou et al. (2011)
Sunflower	Cotton	Approximately 59% weed control efficiency	Kandhro et al. (2014)
Pea, Faba bean	Berseem	Suppressed *Orobanche crenata*	Fernández-Aparicio et al. (2010)
False flax	Field pea	Suppressed *Sonchus oleraceus, Fallopia convolvulus, Matricaria recutita*, etc	Saucke and Ackermann (2006)

T. harzianum. *Purpureocillium lilacinum* has shown effectiveness against nematodes (Pertot et al. 2015). The impacts of plant growth promoting bacteria (PGPB) on disease and nematode management are listed in Table 6. Additionally, bioagents have been successful in suppressing pests in agricultural fields. Some bioagents for crop insect pest management in organic farming are mentioned in Fig. 3. Two strategies to boost the efficacy of natural enemies include altering the ecosystem to favour them over pests and lessening the detrimental effects of pesticides on natural enemies (Pandey et al. 2022).

Benefits and constraints of organic farming practices to mitigate biotic stresses

Organic farming methods offer several advantages for managing biotic stresses in agriculture. These strategies are specifically designed to minimize the use of synthetic pesticides which can pose significant environmental hazards. Instead, organic farming focuses on implementing

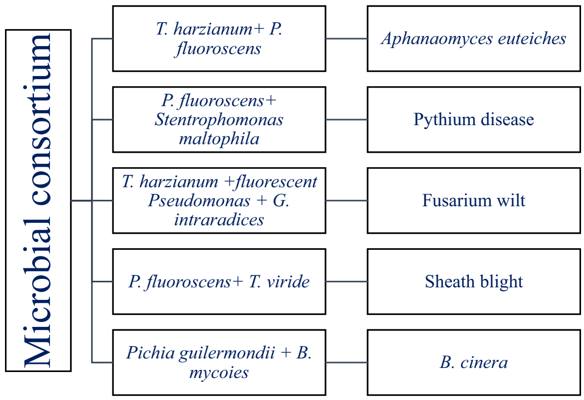

Fig. 2 Some microbial consortium used to manage plant diseases in organic farming (Jain et al. 2013)

more environmentally friendly and sustainable practices to control diseases, weeds, and pests. The benefits of utilizing organic agricultural methods to mitigate biotic stresses include:

1. By eschewing artificial pesticides and herbicides, organic farming helps to reduce the presence of chemical residues in crops. This, in turn, ensures that consumers receive safer and healthier food items. Few non-chemical ways to combat crop disease issues in organic farming are shown in Fig. 4.
2. Organic farming emphasizes soil health improvement through the uses of organic matter, cover crops, and minimal soil disturbance. Healthy soil supports a diverse array of beneficial bacteria and organisms that can naturally control diseases and pests.
3. By eliminating synthetic pesticides, organic farming methods can aid in preventing or delaying the emergence of pests that have developed resistance to these pesticides.
4. Biodiversity thrives on organic farms, with an abundance of beneficial insects and other creatures that can assist in controlling pest populations.
5. Organic farming is dedicated to establishing resilient agricultural systems that uphold soil fertility and foster a healthy ecosystem, thereby reducing long-term reliance on chemical inputs.
6. By abstaining from synthetic pesticides, organic farming contributes to the safety and health of farm workers through limiting their exposure to potentially harmful substances.

Table 6 Impact of plant growth promoting bacteria (PGPB) on disease and nematode management under organic farming

PGPBs	Impact(s)	References
Curtobacterium sp., *Pseudomonas* sp., *Rahnella* sp., *Burkholderia* sp.	Disease suppression of *Fusarium* sp., *Pythium* sp., *Gaeumannomyces* sp. and *Rhizoctonia* sp.	Kandel et al. (2017)
Pseudomonas fluorescens	Induction of systemic resistance in tomato against *Pseudomonas syringae*	Cheng et al. (2017)
Streptomyces sp.	Effective in reducing rice blast disease severity (up to 67%)	Awla et al. (2017)
Pseudomonas aeruginosa	Suppression of fungal pathogens (*Fusarium oxysporum* and *Alternaria solani*)	Paramanandham et al. (2017)
Pantoea agglomerans	Suppression of bacterial blight of mulberry	Xie et al. (2017)
Bacillus cereus, Pseudomonas putida, Serratia proteamaculans	Suppression of root-knot nematode (*Meloidogyne incognita*)	Zhao et al. (2018)
Pantoea sp., *Pseudomonas* sp., *Microbacterium* sp., *Paenibacillus* sp., *Chryseobacterium* sp.	Suppression of *Fusarium oxysporum*	Verma et al. (2018)

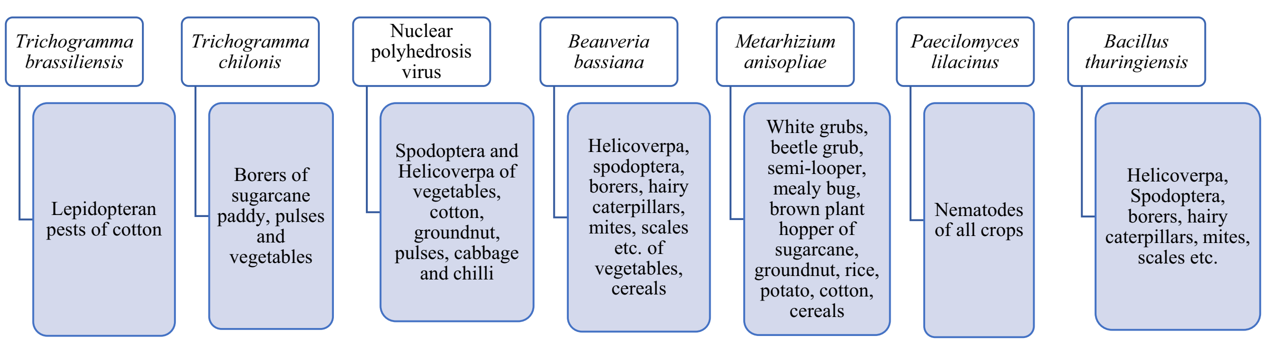

Fig. 3 Some bioagents for crop insect pest management in organic farming (Ghosh et al. 2021)

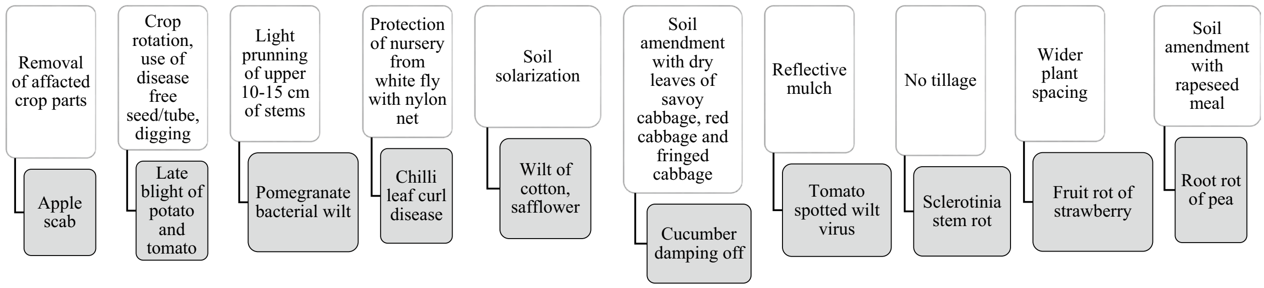

Fig. 4 Some instances of crop disease management in organic farming (Ghosh et al. 2021)

7. Organic farming methods have a lower environmental impact, with less harm to unintended organisms, less contamination of soil and water, and a smaller carbon footprint.

Organic farming offers numerous benefits that extend beyond pest management, contributing to the development of environmentally sustainable and enduring agricultural systems. However, it also has certain constraints when it comes to managing biotic stresses. Some of these constraints include:

1. Organic farmers often rely on non-chemical techniques to control pests, which may not be as efficient as synthetic insecticides.
2. Organic pest control methods can be time-consuming to implement and their efficacy may be influenced by environmental factors. Delayed responses to pest outbreaks may result in significant crop damage.
3. Organic crop varieties may have lower resistance to certain diseases, making them more vulnerable to infections. Conventional breeding programmes utilizing synthetic chemicals often produce disease-resistant crop varieties.
4. Due to restrictions on synthetic herbicides, organic farmers must utilize mechanical and cultural approaches to control weeds. These approaches may require significant labour and may not always be effective, allowing weeds to compete with crops.
5. Effective organic management of weeds, pests, and diseases necessitates a thorough understanding of ecological principles and organic farming practices.
6. Synthetic chemical-using conventional farms next to organic farms pose a risk to organic crops. Contamination from pesticide residues may jeopardize the certification of organic crops.
7. Weather patterns, such as increased humidity and temperature fluctuations, can exacerbate pest and disease pressures in organic systems. Organic practices may be less resilient in extreme weather conditions.

Conclusions

In modern agriculture, extreme weather conditions can result in outbreaks of biotic stresses. In such situations, adopting eco-friendly organic farming approaches can be a beneficial solution to combat these stresses without contributing to global warming. Despite few limitations, organic farming methods are designed to offer sustainable management of biotic stresses through innovative research and modifications. Given the challenges posed by climate change, it is imperative to develop weather-based forecasting models for significant insect pests and crop diseases; monitor key agricultural pests and diseases as well as non-insect pests; develop resistance to significant insect pests and crop diseases; explore the use of plants, microorganisms, and bioagents for their insecticidal activity against crop pests; create biotic stress management plans for important crops in organic farming situations; estimate economically viable threshold values for the major pests, diseases, and weeds etc. It is important to note that effective stress mitigation technique is not achieved through a single method, but rather through the integration of various eco-friendly organic plant protection techniques. In future, further research is utmost needed to standardize plant protection practices, to increase awareness among farmers regarding usage of the eco-safe farming practices, etc., for achieving the successful plant protection against biotic stresses in organic agriculture.

Abbreviations

cm	Centimetre
etc.	Et cetera
et al.	Et alia (and others)
%	Per cent
Fig	Figure
PPN	Plant-parasitic nematode
spp.	Species (plural)
sp.	Species
ITK	Indigenous technical knowledge
BCA	Biocontrol agent
PCA	Phenazine-1-carboxylic acid

M	Molar
PGPB	Plant growth promoting bacteria
kg/ha	Kilo gram per hectare
°C	Degree Celsius
CA	Conservation agriculture
FAO	Food and Agriculture Organization
g	Gram
kg	Kilo gram
AM	Arbuscular mycorrhizal
f sp.	Forma specialis
DAPG	2,4-Diacetylphlorogucinol
Plt	Pyoluteorin
Fe (II)	Ferrous
Fe (III)	Ferric
ml	Millilitre

Acknowledgements
Authors would like to thank the administrations of Ramakrishna Mission Vivekananda Educational and Research Institute and Usha Martin University for allowing authors to conduct the review.

Author contributions
SB conceptualized and written the review. RD helped in material collection and revised the draft. All authors read and approved the final manuscript.

Funding
No funding has been received.

Availability of data and materials
These can be made available based on the request.

Declarations

Ethics approval and consent to participate
There is no ethical issue existed in the article. The article is original, unpublished, and first sent to this journal. Authors approve publication ethics of the journal and has full consent to participate if required.

Consent for publication
Authors have the consent to use the data for the publication of this article.

Competing interests
The authors declare no conflict of interest in this article.

Received: 26 March 2024 Accepted: 8 July 2024
Published online: 16 July 2024

References
Abd-Elgawad MM (2020) Managing nematodes in Egyptian citrus orchards. Bull Natl Res Centre 44(1):41
Abd-Elgawad MMM, Elshahawy IE, Abd-El-Kareem F (2019) Efficacy of soil solarization on black root rot disease and speculation on its leverage on nematodes and weeds of strawberry in Egypt. Bull Natl Res Cent 43:175. https://doi.org/10.1186/s42269-019-0236-1
Abolusoro SA, Odekiya AO, Aremu C, Ige S, Izuogu NB, Abolusoro PF, Erere A, Obaniyi S (2020) Control of root-knot nematode (*Meloidogyne incognita*) in tomato (*Solanum lycopersicum*) crop using siam weed (*Chromolaena odorata*) compost manure. J Hortic Res 28(1):87–92
Abo-Zaid GA, Abdullah AS, Soliman NAM, El-Sharouny EE, Al-Askar AA, Su Y, Abdelkhalek A, Sabry SAF (2023) Evaluation of bio-friendly formulations from siderophore-producing fluorescent Pseudomonas as biocontrol agents for the management of soil-borne fungi, *Fusarium oxysporum* and *Rhizoctonia solani*. Agriculture 13(7):1418
Adane MB (2023) Reduce losses to rice yield caused by bacteria, viruses, or fungi. J Rice Res 11(6):377
Akeme C, Ngosong C, Sumbele S, Aslan A, Tening A, Krah C et al (2021) Different controlling methods of fall armyworm (*Spodoptera frugiperda*) in maize farms of small-scale producers in Cameroon. IOP Conf Ser Earth Environ Sci 911(1):012053
Ali O, Ramsubhag A, Jayaraman J (2021) Biostimulant properties of seaweed extracts in plants: implications towards sustainable crop production. Plants (basel) 10(3):531. https://doi.org/10.3390/plants10030531
Alyokhin A, Nault B, Brown B (2020) Soil conservation practices for insect pest management in highly disturbed agroecosystems—a review. Entomol Exp Appl 168(1):7–27
Amalina F, Abd Razak AS, Krishnan S, Sulaiman H, Zularisam AW, Nasrullah M (2022) Biochar production techniques utilizing biomass waste-derived materials and environmental applications—a review. J Hazard Mater Adv 7:100134
Angon PB, Mondal S, Jahan I, Datto M, Antu UB, Ayshi FJ, Islam MS (2023) Integrated pest management (IPM) in agriculture and its role in maintaining ecological balance and biodiversity. Adv Agric 2023(1):5546373
Ansari M, Devi BM, Sarkar A, Chattopadhyay A, Satnami L, Balu P, Choudhary M, Shahid MA, Jailani AAK (2023) Microbial exudates as biostimulants: role in plant growth promotion and stress mitigation. J Xenobiot 13(4):572–603. https://doi.org/10.3390/jox13040037
Anwar MP, Islam AKMM, Yeasmin S, Rashid MH, Juraimi AS, Ahmed S, Shrestha A (2021) Weeds and their responses to management efforts in a changing climate. Agronomy 11(10):1921. https://doi.org/10.3390/agronomy11101921
Arshad A, Munawar A, Ahmad F, Mastoi MI (2019) Varietal susceptibility of local and hybrid maize against *Atherigona soccata* (Diptera: Muscidae) under field conditions. J Entomol Zool Stud 7:36–41
Awla HK, Kadir J, Othman R, Rashid TS, Hamid S, Wong MY (2017) Plant growth-promoting abilities and biocontrol efficacy of *Streptomyces* sp. UPMRS4 against *Pyricularia oryzae*. Biol Control 112:55–63
Ayilara MS, Adeleke BS, Akinola SA, Fayose CA, Adeyemi UT, Gbadegesin LA, Omole RK, Johnson RM, Uthman QO, Babalola OO (2023) Biopesticides as a promising alternative to synthetic pesticides: a case for microbial pesticides, phytopesticides, and nanobiopesticides. Front Microbiol 14:1040901. https://doi.org/10.3389/fmicb.2023.1040901
Babu AY (2013) Action research report on Subhash Palekar's Zero budget natural farming (undated). Accessed on 11 Aug 2023. Available: http://www.atimysore.gov.in/pdf/action_research.pdf.
Bakhat FZ, Bibi N, Zia Z, Abbas S, Hammad HM, Fahad S, Ashraf MR, Shah GM, Rabbani F, Saeed S (2018) Silicon mitigates biotic stresses in crop plants: a review. Crop Prot 104:21–34
Banik P, Midya A, Sarkar BK, Ghose SS (2006) Wheat and chickpea intercropping systems in an additive series experiment: advantages and weed smothering. Eur J Agron 24(4):325–332. https://doi.org/10.1016/j.eja.2005.10.010
Benvenuti S, Selvi M, Mercati S, Cardinali G, Mercati V, Mazzoncini M (2021) Stale seedbed preparation for sustainable weed seed bank management in organic cropping systems. Sci Hortic 289:110453
Berhe M, Subramanyam B, Chichaybelu M, Demissie G, Abay F, Harvey J (2022) Post-harvest insect pests and their management practices for major food and export crops in east Africa: an Ethiopian case study. InSects 13(11):1068. https://doi.org/10.3390/insects13111068
Biswas S (2020) Zero budget natural farming in India: aiming back to the basics. Int J Environ Clim Change 10(9):38–52
Biswas S, Das R (2023) Double transplanting of rice as a contingency approach to escape climate change impacts. Discov Agric 1(1):8:1-14
Biswas S, Das R, Mahto D, Thakur R (2024) Performance of garden pea (*Pisum sativum* var. *hortense*) under different organic liquid manure applications in Eastern Plateau and Hill zone of India. Vegetos. https://doi.org/10.1007/s42535-024-00908-1
Blaise D, Manikandan A, Verma P, Nalayini P, Chakraborty M, Kranthi KR (2020) Allelopathic intercrops and its mulch as an integrated weed management strategy for rainfed Bt-transgenic cotton hybrids. Crop Prot 135:105214
Bolaji Umar O, Amudalat Ranti L, Shehu Abdulbaki A, Lukman Bola A, Khadijat Abdulhamid A, Ramat Biola M, Oluwagbenga Victor K (2022) Stresses in plants: biotic and abiotic. IntechOpen. https://doi.org/10.5772/intechopen.100501
Boyd NS, Brennan EB, Fennimore SA (2006) Stale seedbed techniques for organic vegetable production. Weed Technol 20(4):1052–1057

Brennan RJB, Glaze-Corcoran S, Robert WICK, Hashemi M (2020) Biofumigation: an alternative strategy for the control of plant parasitic nematodes. J Integr Agric 19:1680–1690

Brooks SA (2011) Influences from long-term crop rotation, soil tillage, and fertility on the severity of rice grain smuts. Plant Dis 95:990–996

Bruns HA, Pettigrew WT, Meredith WR, Stetina SR (2007) Corn yields benefit in rotations with cotton. Online Crop Manag. https://doi.org/10.1094/CM-2007-0424-01-RS

Capinera JL (2002) North American vegetable pests: the pattern of invasion. Am Entomol 48:20–39

Chadfield VGA, Hartley SE, Redeker KR (2022) Associational resistance through intercropping reduces yield losses to soil-borne pests and diseases. New Phytol 235(6):2393–2405. https://doi.org/10.1111/nph.18302

Chauke PB, Nciizah AD, Wakindiki II, Mudau FN, Madikiza S, Motsepe M, Kgakatsi I (2022) No-till improves selected soil properties, phosphorous availability and utilization efficiency, and soybean yield on some smallholder farms in South Africa. Front Sustain Food Syst 6:1009202

Chen P, Tsay TT (2006) Effect of crop rotation on *Meloidogyne* spp. and *Pratylenchus* spp. populations in strawberry fields in Taiwan. J Nematol 38(3):339–344

Cheng X, Etalo DW, van de Mortel JE, Dekkers E, Nguyen L, Medema MH, Raaijmakers JM (2017) Genome-wide analysis of bacterial determinants of plant growth promotion and induced systemic resistance by *Pseudomonas fluorescens*. Environ Microbiol 19:4638–4656

Choudhary VK, Bhambri MC (2013) Crop productivity, water use and weed control efficiency of capsicum (*Capsicum annum* L.) under drip irrigation and mulching. J Agric Phys 13:133–138

Choudhary VK, Naidu D, Dixit A (2021) Weed prevalence and productivity of transplanted rice influences by varieties, weed management regimes and row spacing. Arch Agron Soil Sci. https://doi.org/10.1080/03650340.2021.1937606

Corre-Hellou G, Dibet A, Hauggaard-Nielsen H, Crozat Y, Gooding M, Ambus P et al (2011) The competitive ability of pea–barley intercrops against weeds and the interactions with crop productivity and soil N availability. Field Crops Res 122(3):264–272. https://doi.org/10.1016/j.fcr.2011.04.004

D'Addabbo T, Laquale S, Perniola M, Candido V (2019) Biostimulants for plant growth promotion and sustainable management of phytoparasitic nematodes in vegetable crops. Agronomy 9:616

Dadlani M, Gupta A, Sinha SN, Kavali R (2023) Seed storage and packaging. In: Dadlani M, Yadava DK (eds) Seed science and technology. Springer, Singapore. https://doi.org/10.1007/978-981-19-5888-5_11

Dar SA, Mir SH, Wani SH, Dolkar T, Abid S, Dawa T (2021) Insect pest management in organic agriculture: a fast growing approach of 21st century. Int J Agric Environ Sustain 3(1):1–6

Das R, Biswas S (2022) Changes in biochemical and enzymatic activities with ageing in seeds of different sizes of sunflower (*Helianthus annuus* L.) under invigoration treatments. Plant Physiol Rep 27:81–95. https://doi.org/10.1007/s40502-021-00610-3

de la Fuente EB, Oreja FH, Lenardis AE, Fuentes MT, Agosti B, Barrio A, Barberis S, Robredo J, Gil A, Marzetti M, Niccia E (2021) Intensification of crop rotation affecting weed communities and the use of herbicides in the rolling Pampa. Heliyon. https://doi.org/10.1016/j.heliyon.2021.e06089

Dentika P, Ozier-Lafontaine H, Penet L (2021) Weeds as pathogen hosts and disease risk for crops in the wake of a reduced use of herbicides: evidence from yam (*Dioscorea alata*) fields and Colletotrichum pathogens in the tropics. J Fungi (basel) 7(4):283. https://doi.org/10.3390/jof7040283

Derpsch R, Friedrich T, Landers JN, Rainbow R, Reicosky DC, Sa JCM, et al. (2011) About the necessity of adequately defining no-tillage—a discussion paper. In: Proceedings of the 5th world congress of conservation agriculture, pp 1–4

Do EA, Gries CM (2021) Beyond homeostasis: potassium and pathogenesis during bacterial infections. Infect Immun. https://doi.org/10.1128/IAI.00766-20

Dutta TK, Khan MR, Phani V (2019) Plant-parasitic nematode management via biofumigation using brassica and non-brassica plants: current status and future prospects. Curr Plant Biol 17:17–32

Dwivedi N, Dwivedi SK (2020) Soil solarization: an ecofriendly technique to eradicate soil Fusaria causing wilt disease in guava (*Psidium guajava*). Int J Fruit Sci 20(sup3):S1765–S1772

El-Saadony MT, Saad AM, Soliman SM, Salem HM, Ahmed AI, Mahmood M, El-Tahan AM, Ebrahim AA, El-Mageed TA, Negm SH, Selim S, Babalghith AO, Elrys AS, El-Tarabily KA, AbuQamar SF (2022) Plant growth-promoting microorganisms as biocontrol agents of plant diseases: mechanisms, challenges and future perspectives. Front Plant Sci 13:923880

El-Shafie HAF (2019) Insect pest management in organic farming system. IntechOpen. https://doi.org/10.5772/intechopen.84483

Erdei AL, David AB, Savvidou EC, Džemedžionaitė V, Chakravarthy A, Molnár BP, Dekker T (2024) The push–pull intercrop Desmodium does not repel, but intercepts and kills pests. Elife 13:e88695

FAO (2014) What is conservation agriculture? Food and Agriculture Organization CA website http://www.fao.org/ag/ca/1a.thml. Accessed 4 July 2023

Fernández-Aparicio M, Emeran AA, Rubiales D (2010) Inter-cropping with berseem clover (*Trifolium alexandrinum*) reduces infection by *Orobanche crenata* in legumes. Crop Prot 29:867–871

Fernando M, Shrestha A (2023) The potential of cover crops for weed management: a sole tool or component of an integrated weed management system? Plants 12(4):752

Fu X, Wu X, Zhou X, Liu S, Shen Y, Wu F (2015) Companion cropping with potato onion enhances the disease resistance of tomato against *Verticillium dahliae*. Front Plant Sci 6:726

Gaba S, Gabriel E, Chadœuf J, Bonneu F, Bretagnolle V (2016) Herbicides do not ensure for higher wheat yield, but eliminate rare plant species. Sci Rep 6:30112. https://doi.org/10.1038/srep30112

Gao X, Wu M, Xu R, Wang X, Pan R, Kim HJ, Liao H (2014) Root interactions in a maize/soybean intercropping system control soybean soil-borne disease, red crown rot. PLoS ONE 9:e95031

Gfeller V, Huber M, Förster C, Huang W, Köllner TG, Erb M (2019) Root volatiles in plant-plant interactions I: high root sesquiterpene release is associated with increased germination and growth of plant neighbours. Plant Cell Environ 42(6):1950–1963. https://doi.org/10.1111/pce.13532

Ghosh PK, Jeer M, Sivalingam PN, Parmeshwari B, Singh HK, Choudhary VK, Kumar KK, Sahu B, Muthappa SK, Dixit A, Das A (2021) Agronomic innovations in biotic stress management and its combined effect with abiotic stresses in crop production. Indian J Agron 66(5th IAC Special issue):S237–S257

Gill HK, Aujla IS, De Bellis L, Luvisi A (2017) The role of soil solarization in India: how an unnoticed practice could support pest control. Front Plant Sci 8:1515

Gohain S, Neog M, Bhattacharyya HC (2019) Innovative traditional pest management practices in horticultural crops. Asian Agric Hist 23(1):61–64

Guzmán MG, Cellini F, Fotopoulos V, Balestrini R, Arbona V (2022) New approaches to improve crop tolerance to biotic and abiotic stresses. Physiol Plant 174(1):e13547. https://doi.org/10.1111/ppl.13547

Hamid K (2011) Crop rotations for managing soil-borne plant diseases. Afr J Food Sci Technol 2(1):001–009

Hanschen FS, Winkelmann T (2020) Biofumigation for fighting replant disease: a review. Agronomy 10(3):425. https://doi.org/10.3390/agronomy10030425

Hasan M, Ahmad-Hamdani MS, Rosli AM, Hamdan H (2021) Bioherbicides: an eco-friendly tool for sustainable weed management. Plants (basel) 10(6):1212. https://doi.org/10.3390/plants10061212

He DC, He MH, Amalin DM, Liu W, Alvindia DG, Zhan J (2021) Biological control of plant diseases: an evolutionary and eco-economic consideration. Pathogens 10(10):1311

Iacomino G, Idbella M, Laudonia S, Vinale F, Bonanomi G (2022) The suppressive effects of biochar on above- and belowground plant pathogens and pests: a review. Plants 11(22):3144

Ippolito JA, Cui L, Kammann C, Wrage-Mönnig N, Estavillo JM, Fuertes-Mendizabal T, Borchard N (2020) Feedstock choice, pyrolysis temperature and type influence biochar characteristics: a comprehensive meta-data analysis review. Biochar 2:421–438

Iqbal J, Cheema ZA, An M (2007) Intercropping of field crops in cotton for the management of purple nutsedge (*Cyperus rotundus* L.). Plant Soil 300:163–171. https://doi.org/10.1007/s11104-007-9400-8

Iquebal MA, Mishra P, Maurya R, Jaiswal S, Rai A, Kumar D (2021) Centenary of soil and air borne wheat karnal bunt disease research: a review. Biology (basel) 10(11):1152. https://doi.org/10.3390/biology10111152

Jacobsen SK, Sigsgaard L, Johansen AB et al (2022) The impact of reduced tillage and distance to field margin on predator functional diversity. J Insect Conserv 26:491–501
Jain A, Singh A, Singh BN, Singh S, Upadhyay RS, Sarma BK, Singh HB (2013) Biotic stress management in agricultural crops using microbial consortium. In: Maheshwari DK (ed) Bacteria in agrobiology: disease management. Springer, Berlin, pp 427–448. https://doi.org/10.1007/978-3-642-33639-3_16
Jalli M, Huusela E, Jalli H, Kauppi K, Niemi M, Himanen S, Jauhiainen L (2021) Effects of crop rotation on spring wheat yield and pest occurrence in different tillage systems: a multi-year experiment in Finnish growing conditions. Front Sustain Food Syst 5:647335
Jankielsohn A (2018) The importance of insects in agricultural ecosystems. Adv Entomol 6(2):62–73
Jasrotia P, Kumari P, Malik K, Kashyap PL, Kumar S, Bhardwaj AK, Singh GP (2023) Conservation agriculture based crop management practices impact diversity and population dynamics of the insect-pests and their natural enemies in agroecosystems. Front Sustain Food Syst 7:1173048
Jeer M, Sahu MP, Choudhary VK (2021) Novel approaches for biotic stress management in the emerging production system. In: Ghosh PK, Kumar P, Chakraborty D, Mandal D, Sivalingam PN (eds) Innovations in agriculture for a self-reliant India. CRC Press, Cambridge, pp 305–329
Jeer M, Suman K, Telugu UM, Voleti SR, Padmakumari AP (2018) Rice husk ash and imidazole application enhances silicon availability to rice plants and reduces yellow stem–borer damage. Field Crops Res 224:60–66
Jiaxing L, Jingxiu X, Zengpeng G, Kun D, Yan D (2021) Nitrogen supply and intercropping control of Fusarium wilt in faba bean depend on organic acids exuded from the roots. Sci Rep 11:9589
Jones RAC (2021) Global plant virus disease pandemics and epidemics. Plants (basel) 10(2):233. https://doi.org/10.3390/plants10020233
Kahl HM, Leslie AW, Hooks CRR (2019) Effects of red clover living mulch on arthropod herbivores and natural enemies, and cucumber yield. Ann Entomol Soc Am 112:356–364
Kalita S, Hazarika LK (2019) Indigenous technical knowledge (ITK) on storage pest management and ritual-based farming practices in Assam. Asian Agric Hist 23(1):1–14
Kanatas P, Travlos I, Gazoulis I, Antonopoulos N, Tataridas A, Mpechliouli N, Petraki D (2022) Biostimulants and herbicides: a promising approach towards Green Deal implementation. Agronomy 12(12):3205
Kandel SL, Firrincieli A, Joubert PM, Okubara PA, Leston ND, McGeorge KM, Doty SL (2017) An in vitro study of bio-control and plant growth promotion potential of Salicaceae endophytes. Front Microbiol 8:386
Kandhro MN, Tunio S, Rajpar I, Chachar Q (2014) Allelopathic impact of sorghum and sunflower intercropping on weed management and yield enhancement in cotton. Sarhad J Agric 30(3):311–318
Kaspary TE, Roma-Burgos N, Merotto A Jr (2020) Snorkeling strategy: tolerance to flooding in rice and potential application for weed management. Genes (basel) 11(9):975. https://doi.org/10.3390/genes11090975
Kaur P, Kaur K, Singh H (2020) Role of micro-irrigation in vegetable crops. Int J Agric Innov Res 9(2):89–96
Kelly L (2020) Keeping a close eye on diseases this season. The Beatsheet, Queensland government. Published on February 25, 2020. Accessed from: https://thebeatsheet.com.au/keeping-a-close-eye-on-diseases-this-season.
Khalil SK, Mehmood T, Rehman A, Wahab S, Khan AZ, Zubair M et al (2010) Utilization of allelopathy and planting geometry for weed management and dry matter production of maize. Pak J Bot 42(2):791–803
Khamare Y, Chen J, Marble SC (2022) Allelopathy and its application as a weed management tool: a review. Front Plant Sci 13:1034649. https://doi.org/10.3389/fpls.2022.1034649
Khasraw MN, Kareem SH, Mustafa KM, Aziz OK, Arif M, Anwar A, Hussain M (2023) Integrated weed management in wheat by using sowing time, seed rate and herbicides. Adv Weed Sci 41:e020230037
Kousta A, Papastylianou P, Travlos I, Mavroeidis A, Kakabouki I (2023) Effect of fertilization and weed management practices on weed diversity and hemp agronomic performance. Agronomy 13(4):1060. https://doi.org/10.3390/agronomy13041060
Kumar R, Cheema HK (2020) Restricting lepidopteran herbivory through trap cropping and bird perches in Egyptian clover (*Trifolium alexandrinum* L.). Egypt J Biol Pest Control 30(1):11
Kumar S, Bhowmick MK, Ray P (2021) Weeds as alternate and alternative hosts of crop pests. Indian J Weed Sci 53(1):14–29
Kumar V, Kumar V, Yadav P (2020) Importance of summer ploughing for sustainable agriculture. Int J Trend Res Dev 7(3):336–337
Kumara AKM, Shakywar RC, Chand G, Hiremath R, Sehgal M, Malik M (2021) Ecological engineering as a pest management tool in horticultural ecosystems. Int J Agric Environ Sustain 3(1):8–16
Kumari S, Sood AK, Sharma PK (2022) Toxicity of natural and organic insecticidal products to greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Aleyrodidae: Hemiptera). Himachal J Agric Res 48(2):307–311
La Spada F, Aloi F, Coniglione M, Pane A, Cacciola SO (2021) Natural biostimulants elicit plant immune system in an integrated management strategy of the postharvest green mold of orange fruits incited by *Penicillium digitatum*. Front Plant Sci 12:684722. https://doi.org/10.3389/fpls.2021.684722
Lahlali R, Ezrari S, Radouane N, Kenfaoui J, Esmaeel Q, El Hamss H, Belabess Z, Barka EA (2022) Biological control of plant pathogens: a global perspective. Microorganisms 10(3):596
Li Y, Song D, Liang S, Dang P, Qin X, Liao Y, Siddique KHM (2020) Effect of no-tillage on soil bacterial and fungal community diversity: a meta-analysis. Soil Tillage Res 204:104721
Lichtenberg EM, Milosavljević I, Campbell AJ, Crowder DW (2023) Differential effects of soil conservation practices on arthropods and crop yields. J Appl Entomol 147(10):931–940
Liu H, Zhan J, Hussain S, Nie L (2019) Grain yield and resource use efficiencies of upland and lowland rice cultivars under aerobic cultivation. Agronomy 9(10):591. https://doi.org/10.3390/agronomy9100591
Long RF, Goodell PB, Baldwin RA, Frate CA, Godfrey LD, Orloff SB, Canevari WM, Davis RM, Getts TJ, Grettenberger IM, Leinfelder-Miles M, Natwick ET, Putnam DH, Rethwisch MD, Westerdahl BB, Wilson RG (2024) Crop rotation impacts on pests. UC IPM Pest Management Guidelines: Alfalfa. UC ANR Publication 3430. Davis, CA. Accessed from: https://ipm.ucanr.edu/agriculture/alfalfa/crop-rotation-impacts-on-pests/#gsc.tab=0
Manghwar H, Zaman W (2024) Plant biotic and abiotic stresses. Life (basel) 14(3):372. https://doi.org/10.3390/life14030372
Mhatre PH, Divya KL, Venkatasalam EP, Bairwa A, Sudha R, Saranya C, Sharma S (2021) Evaluation of trap crop, *Solanum sisymbriifolium* and antagonistic crops against potato cyst nematodes, *Globodera* spp. S Afr J Bot 138:242–248
Midzi J, Jeffery DW, Baumann U, Rogiers S, Tyerman SD, Pagay V (2022) Stress-induced volatile emissions and signalling in inter-plant communication. Plants 11(19):2566
Mishra J, Dutta V, Arora NK (2020) Biopesticides in India: technology and sustainability linkages. 3 Biotech 10(5):210. https://doi.org/10.1007/s13205-020-02192-7
Mokrini F, Viaene N, Waeyenberge L, Afechtal M, Essarioui A, Moens M (2017) The importance, biology and management of cereal cyst nematodes (*Heterodera* spp.): a review. Revue Marocaine Des Sciences Agronomiques Et Vétérinaires 5(4):414–421
Monteiro A, Santos S (2022) Sustainable approach to weed management: the role of precision weed management. Agronomy 12(1):118. https://doi.org/10.3390/agronomy12010118
Muluneh MG (2021) Impact of climate change on biodiversity and food security: a global perspective—a review article. Agric Food Secur 10:36. https://doi.org/10.1186/s40066-021-00318-5
Naeem M (2011) Studying weed dynamics in wheat (*Triticum aestivum* L.)-canola (*Brassica napus* L.) intercropping system. Doctoral dissertation, Department of Agronomy, University of Agriculture, Faisalabad, Pakistan
Nalayini P, Blaise D, Mundafale HR (2023) Stale seed bed technique and leguminous cover crops as components of integrated weed management in irrigated cotton. Indian J Weed Sci 55(1):46–49
Nath CP, Singh RG, Choudhary VK, Datta D, Nandan R, Singh SS (2024) Challenges and alternatives of herbicide-based weed management. Agronomy 14(1):126
Nawaz M, Sun J, Shabbir S, Khattak WA, Ren G, Nie X, Bo Y, Javed Q, Du D, Sonne C (2023) A review of plants strategies to resist biotic and abiotic environmental stressors. Sci Total Environ 900:165832
Olasantan FO, Lucas EO, Ezumah HC (1994) Effects of intercropping and fertilizer application on weed control and performance of cassava and maize. Field Crop Res 39(2–3):63–69. https://doi.org/10.1016/0378-4290(94)90009-4

Omotayo OE, Eegunranti AM (2023) Effect of soil solarization on tomato (*Solanum lycopersicum* L.) growth and impact on native microbial diversity of farm soil in Nigeria. Egypt J Biol Pest Control 33:6. https://doi.org/10.1186/s41938-023-00653-8
Omovbude S, Udensi EU, Orluchkwu JA (2017) Effect of intercropping on weed suppression and maize (*Zea mays* L.) yield in a humid forest agroecology of South-Eastern Nigeria. IOSR J Agric Vet Sci 10:40–46
Padmavathi CH, Padmaja PM (2022) Insect resistance in field crops. Indian J Entomol 84:1–28
Palekar S (2014) Available: http://www.palekarzerobudgetspiritualfarming.org/ Retrieved on 12th May, 2023.
Pandey R (2023) Controlling Tobacco diseases: an overview of black shank and Fusarium wilt. Int J Appl Sci Biotechnol 11(1):1–7
Pandey S, Johnson AC, Xie G, Gurr GM (2022) Pesticide regime can negate the positive influence of native vegetation donor habitat on natural enemy abundance in adjacent crop fields. Front Ecol Evol 10:815162
Paramanandham P, Rajkumari J, Pattnaik S, Bus S (2017) Biocontrol potential against *Fusarium oxysporum* f. sp. *lycopersici* and *Alternaria solani* and tomato plant growth due to plant growth promoting rhizobacteria. Int J Veg Sci 23:294–303
Patel LC (2013) Innovative trap for rat control with bamboo materials. Front Farming 1(3):33
Pathak VM, Verma VK, Rawat BS, Kaur B, Babu N, Sharma A, Dewali S, Yadav M, Kumari R, Singh S, Mohapatra A, Pandey V, Rana N, Cunill JM (2022) Current status of pesticide effects on environment, human health and its eco-friendly management as bioremediation: a comprehensive review. Front Microbiol 13:962619. https://doi.org/10.3389/fmicb.2022.962619
Patil AG, Neelambika M, Nagendra K, Rajkumar M, Singh VP (2020) A review of weed management in different crops. Int J Chem Stud 8(4):4013–4023
Pertot I, Alabouvette C, Esteve EH, Franca S (2015) The use of microbial biocontrol agents against soil-borne diseases. Retrieved from European Commission EIP-AGRI Focus Group. https://ec.europa.eu/eip/agriculture/sites/agrieip/files/8_eip_sbd_mp_biocontrol_final.pdf
Potato News Today (2021) The Rhizoctonia threat: British potato growers advised on control measures after cold and dry spring. Published on May 13, 2021. Accessed from: https://www.potatonewstoday.com/2021/05/13/the-rhizoctonia-threat-british-potato-growers-advised-on-control-measures-after-cold-and-dry-spring
Prajapati S, Kumar N, Kumar S, Maurya S (2020) Biological control a sustainable approach for plant diseases management: a review. J Pharmacogn Phytochem 9(2):1514–1523
Rahman L, Chan KY, Heenan DP (2007) Impact of tillage, stubble management and crop rotation on nematode populations in a long-term field experiment. Soil Tillage Res 95:110–119
Rahman M, Islam T, Jett L, Kotcon J (2021) Biocontrol agent, biofumigation, and grafting with resistant rootstock suppress soil-borne disease and improve yield of tomato in West Virginia. Crop Prot 145:105630
Rajput MA, Rajput NA, Syed RN, Lodhi AM, Que Y (2021) Sugarcane Smut: current knowledge and the way forward for management. J Fungi (basel) 7(12):1095. https://doi.org/10.3390/jof7121095
Rana SS, Rana MC (2019) Principles and practices of weed management. Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, p 138
Reddy PP (2017a) Crop rotation. Agro-ecological approaches to pest management for sustainable agriculture. Springer, Singapore, pp 229–242
Reddy PP (2017b) Trap cropping. Agro-ecological approaches to pest management for sustainable agriculture. Springer, Singapore, pp 133–147
Rizvi R, Singh G, Safiuddin D, Ali Ansari R, Ali Tiyagi S, Mahmood I (2015) Sustainable management of root–knot disease of tomato by neem cake and *Glomus fasciculatum*. Cogent Food Agric 1:1008859
Rosskopf E, Di Gioia F, Hong JC, Pisani C, Kokalis-Burelle N (2020) Organic amendments for pathogen and nematode control. Annu Rev Phytopathol 58:277–311
Roy D (2022) Zero budget natural farming: an agricultural revolution. Biotica Res Today 4(9):625–628
Roy S, Rathor A, Sarkar S, Roy K (2015) Use of ITK in plant protection. Pop Kheti 3(2):75–78
Saeed Q, Xiukang W, Haider FU, Kučerik J, Mumtaz MZ, Holatko J, Naseem M, Kintl A, Ejaz M, Naveed M, Brtnicky M, Mustafa A (2021) Rhizosphere bacteria in plant growth promotion, biocontrol, and bioremediation of contaminated sites: a comprehensive review of effects and mechanisms. Int J Mol Sci 22(19):10529. https://doi.org/10.3390/ijms221910529
Saha B, Dutta P (2013) Indigenous methods of crop protection: an Indian Scenario. In: Banik S (ed) Current concepts in crop protection. Stadium Press, New Delhi, pp 411–429
Salman A, Arif M, Ali M, Afzaal M, Saeed G, Bilal M, Zaheer S (2020) Biochar and integrated phosphorus management suppress weed density in maize crop. Pak J Weed Sci Res 26(4):491
Saucke H, Ackermann K (2006) Weed suppression in mixed cropped grain peas and false flax (*Camelina sativa*). Weed Res 46(6):453–461. https://doi.org/10.1111/j.1365-3180.2006.00530.x
Saudy HS (2015) Maize–cowpea intercropping as an ecological approach for nitrogen-use rationalization and weed suppression. Arch Agron Soil Sci 61(1):114. https://doi.org/10.1080/03650340.2014.920499
Scavo A, Mauromicale G (2020) Integrated weed management in herbaceous field crops. Agronomy 10(4):466
Senthilkumar D, Murali AP, Chinnusamy C, Bharathi C, Yalabela L (2019) Stale seed bed techniques as successful weed management practice. J Pharmacogn Phytochem SP2:120–123
Shakrawar M, Naberia S, Pande AK (2018) Indigenous technical knowledge for pest, disease and weed management in agriculture. Int J Chem Stud 6(4):497–498
Shan Z, Zhou S, Shah A, Arafat Y, Arif Hussain Rizvi S, Shao H (2023) Plant allelopathy in response to biotic and abiotic factors. Agronomy 13(9):2358. https://doi.org/10.3390/agronomy13092358
Sharma N, Rayamajhi M (2022) Different aspects of weed management in maize (*Zea mays* L.): a brief review. Adv Agric. https://doi.org/10.1155/2022/7960175
Shekhar M, Shivashankar E, Pandey SK (2024) Crop rotation and intercropping techniques. In: Modern concept in agronomy (Edition I). ND Global Publication House. https://doi.org/10.5281/zenodo.11051201
Shi Q, Cai X, Zhang Z, Song W, Liang C, Duan F, Zhao H (2023) The identification, characterization, and management of *Rotylenchulus reniformis* on Cucumis melo in China. Phytopathol Res 5(1):58
Shukla S, Upadhyay D, Mishra A, Jindal T, Shukla K (2022) Challenges faced by farmers in crops production due to fungal pathogens and their effect on Indian economy. In: Rajpal VR, Singh I, Navi SS (eds) Fungal diversity, ecology and control management. Fungal biology. Springer, Singapore. https://doi.org/10.1007/978-981-16-8877-5_24
Singh AK, Singh BK, Tomar RKS (2018) Evaluation of different modules against chickpea (*Cicer arietinum* L.) diseases. Plant Arch 18:811–814
Singh BK, Delgado-Baquerizo M, Egidi E et al (2023) Climate change impacts on plant pathogens, food security and paths forward. Nat Rev Microbiol 21:640–656. https://doi.org/10.1038/s41579-023-00900-7
Singh MK, Mishra A, Khanal A (2019) Effects of sowing dates and mulching on growth and yield of wheat and weeds (*Phalaris minor* Retz.). Bangladesh J Bot 48:75–84
Skendžić S, Zovko M, Živković IP, Lešić V, Lemić D (2021) The impact of climate change on agricultural insect pests. Insects 12(5):440. https://doi.org/10.3390/insects12050440
Sow S, Ranjan S (2021) Indigenous technical knowledge (ITK) for sustainable agriculture in India. Agric Food E-Newsl 3(1):31–35
Stewart CJ, Marble SC, Jackson BE, Pearson BJ, Wilson PC (2018) Effects of three fertilization methods on weed growth and herbicide performance in soilless nursery substrates. J Environ Hortic 36:133–139
Tao R, Liang YC, Wakelin SA, Chu GX (2015) Supplementing chemical fertilizer with an organic component increases soil biological function and quality. Appl Soil Ecol 96:42–51
Thakur K, Sharma A, Sharma K (2021) Management of agricultural insect pests with physical control methods. Pharma Innov J 10(6):306–314
Travlos I, Gazoulis I, Kanatas P, Tsekoura A, Zannopoulos S, Papastylianou P (2020) Key factors affecting weed seeds' germination, weed emergence, and their possible role for the efficacy of false seedbed technique as weed management practice. Front Agron 2:1
Ul-Allah S, Azeem A, Sher A, Ijaz M, Sattar A, Naeem M, Ullah I (2023) Plant breeding approaches in developing stress tolerance. In: Biology and biotechnology of environmental stress tolerance in plants. Apple Academic Press, pp 167–186
Verma SK, Kingsley K, Bergen M, English C, Elmore M, Kharwar RN, White JF (2018) Bacterial endophytes from rice cut grass (*Leersia oryzoides* L.) increase growth, promote root gravitropic response, stimulate root

hair formation, and protect rice seedlings from disease. Plant Soil 422:223–238
Vidotto F, Fogliatto S, Milan M, Ferrero A (2016) Weed communities in Italian maize fields as affected by pedoclimatic traits and sowing time. Eur J Agron 74:38–46
Viradiya JS, Gangwar GP (2022) Management of powdery mildew and aphid in organically grown Indian mustard (*Brassica juncea* L.) through different oils. J Appl Nat Sci 14(3):861–867
Volsi B, Higashi GE, Bordin I et al (2022) The diversification of species in crop rotation increases the profitability of grain production systems. Sci Rep 12:19849. https://doi.org/10.1038/s41598-022-23718-4
Wada N, Berry PA, Hill B, Carol MS, Parke JL (2024) Soil solarization as a non-chemical weed control method in tree nursery production systems of the Pacific Northwest, USA. Front Agron 5:1321372
Xie J, Shu P, Strobel G, Chen J, Wei J, Xiang Z, Zhou Z (2017) Pantoea agglomerans SWg2 colonizes mulberry tissues, promotes disease protection and seedling growth. Biol Control 113:9–17
Yaman KP (2021) Physiological stress in agricultural crops: an overview. Biol Forum Int J 13(1):277–292
Yang Y, Chen T, Xiao R et al (2022) A quantitative evaluation of the biochar's influence on plant disease suppress: a global meta-analysis. Biochar 4:43
Yatoo AM, Ali MN, Baba ZA et al (2021) Sustainable management of diseases and pests in crops by vermicompost and vermicompost tea. A review. Agron Sustain Dev 41:7. https://doi.org/10.1007/s13593-020-00657-w
Yendyo S, Ramesh GC, Pandey BR (2017) Evaluation of *Trichoderma* spp., *Pseudomonas fluorescens* and *Bacillus subtilis* for biological control of Ralstonia wilt of tomato. F1000Research 6:2028
Yuliar NYA, Toyota K (2015) Recent trends in control methods for bacterial wilt diseases caused by *Ralstonia solanacearum*. Microbes Environ 30(1):1–11
Zhang L, Liu Z, Song Y, Sui J, Hua X (2024) Advances in the involvement of metals and metalloids in plant defense response to external stress. Plants 13(2):313
Zhao D, Zhao H, Zhao D, Zhu X, Wang Y, Duan Y, Chen L (2018) Isolation and identification of bacteria from rhizosphere soil and their effect on plant growth promotion and root-knot nematode disease. Biol Control 119:12–19
Zhu S, Morel JB (2019) Molecular mechanisms underlying microbial disease control in intercropping. Mol Plant Microbe Interact 32(1):20–24

Publisher's Note