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Agriculture Science: Research and Review Volume VI

Editors

Dr. Parashurama T. R

Dr. Y. Linthoingambi Devi

Mr. Asif Mohi Ud Din Rather

Mr. Sachin Kumar Yadav

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Editors

Dr. Parashurama T. R

Panchavati Research Academy for Nature (PRANA), Kalamaji,

Central Western Ghats, Shimoga

Dr. Y. Linthoingambi Devi

Department of Genetics and Plant Breeding, College of Agriculture, IGKV,

Raipur, Chhattisgarh

Mr. Asif Mohi Ud Din Rather

Division of Vegetable Science,

Sher-e-Kashmir University of Agricultural Sciences and Technology,

Kashmir

Mr. Sachin Kumar Yadav

Department of Entomology,

Chandra Shekhar Azad University of Agriculture & Technology Kanpur,

U.P.

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PREFACE

We are delighted to publish our book entitled ***"Agricultural Science: Research and Reviews Volume VI".*** *This book is the compilation of esteemed articles of acknowledged experts in the fields of basic and applied agricultural science.*

The Indian as well as world population is ever increasing. Hence, it is imperative to boost up agriculture production. This problem can be turned into opportunity by developing skilled manpower to utilize the available resources for food security. Agricultural research can meet this challenge. New technologies have to be evolved and taken from lab to land for sustained yield. The present book on agriculture is to serve as a source of information covering maximum aspects, which can help understand the topics with eagerness to study further research. We developed this digital book with the goal of helping people achieve that feeling of accomplishment.

The articles in the book have been contributed by eminent scientists, academicians. Our special thanks and appreciation goes to experts and research workers whose contributions have enriched this book. We thank our publisher Bhumi Publishing, India for taking pains in bringing out the book.

Finally, we will always remain a debtor to all our well-wishers for their blessings, without which this book would not have come into existence.

Editors

CONTENT

POTENTIAL OF TRICHOGRAMMA AS A PARASITOID: PRESENT STATUS AND PERSPECTIVES

J. Komal[1], Aarthi Nekkanti[2], Sujatha G S[3], Aradhana Panda[4], Nikita Negi[2] and Deepak Kumar Mahanta[3]*

[1]Department of Entomology,
Navsari Agricultural University (NAU), Gujarat-396450
[2]Department of Entomology,
Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh-492012
[3]Department of Entomology,
Dr. Rajendra Prasad Agriculture University, Pusa, Bihar-848125
[4]Department of Entomology, Sher-e-Kashmir University of Agricultural Sciences and Technology, Wadura, Sopore, Jammu and Kashmir-193201
*Corresponding author E-mail- deepakmahanta36@gmail.com

Abstract:

Over the last 50 years, significant advances have been made to the release of Trichogramma for biological control of lepidopterous pests. To be economically successful, all Trichogramma initiatives must meet the four factors listed below. The best population is chosen based on inter- and intraspecific variation, as well as existing criteria of parasitoid quality. Although mass rearing includes both host and parasitoid components, the emphasis is currently on constructing artificial systems. Trichogramma distribution requires supported extension and improved technologies. Field strategies differ depending on the intended strategy (inundative or inoculative), the timing, frequency, and rate of release, and the numerous elements that effect release, including as weather, crop, host, predation, pesticides, and dispersion. The previous difficulties in analysing Trichogramma efficacy should be alleviated by new rules for harmonising terminology and metrics.

Keywords: Trichogramma**,** inundative, inoculative, release

Introduction:

For more than a century, biological control technologies have been used to provide long-term control of a variety of key agricultural pests. Trichogramma egg parasitoids (Hymenoptera: Trichogrammatidae) are employed globally for inoculative and inundative releases against lepidopteran pests, and mass-production facilities have been built in numerous countries. *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) has been successfully controlled using Trichogramma spp. on cotton and tomato in India. Farmers are advised to employ Trichogramma spp. against this pest both as a single biocontrol agent and as part of an integrated pest management programme. In India, a variety of business companies and governmental institutes have begun to sell biocontrol agents such as Trichogramma spp. since 1981. Trichogramma egg parasitoids have been employed effectively in many regions of the world, mostly by inundative releases. Trichogramma species parasitize insect eggs, particularly lepidopterous pest eggs, and are mostly used in biological control programmes. Before causing any damage to the host plants, they examine the abundance of insect pests at the egg stage. Trichogrammatidae members are extremely small, measuring between 0.2 to 1.0 mm in length. Trichogramma egg parasitoids are easily distinguished because adult females have antennae with a 2-segmented funicle and one segmented club, fore wings with sigmoid venation, and vein track RS1. Westwood (1833) established the genus Trichogramma based on the type species, *Trichogramma evanescens*. Based on discal ciliation of the fore wings, Ashmead (1904a) classified the Trichogrammatidae as a family and further separated it into two subfamilies: Trichogramminae and Oligositinae. Trichogramma spp. have been identified as possible egg parasitoids of numerous major insect pests of agricultural crops and forest tree species, including teak, poplar, and shisham defoliators. Quality control of mass manufactured Trichogramma spp. has garnered increasing attention in recent years, particularly in Western Europe and North America.

Historical view

Trichogramma release for biological control of lepidopterous pests has been discussed for more than a century, but mass breeding of these hymenopterous parasitoids was not advocated in North America until the 1920s. During the 1930s, Flanders' work (1930) sparked interest, but with the development of chemical pesticides, this interest faded. Trichogramma was primarily developed as a biological control agent by scientists in the former Soviet Union (from 1937) and China (from 1949). In the 1960s, Europeans and Americans revived Trichogramma research; in the 1970s, they began mass-rearing and release. (Bigler, 1986). Although the genus Trichogramma is not the only one employed in this method, investigations with these minute egg parasitoids have contributed significantly to our understanding of inundative release. Simultaneously with Stinner's review. The establishment of a worldwide research compendium marked the beginning of an interchange of knowledge among scientists in North America, Europe, the former Soviet Union, and China. This interaction sparked an outpouring of study that is still going on today. Since 1982 (Voegelt *et al.,* 1988), international symposia with published proceedings have been organised every four years, and informal discussions have been conducted at the last three International Congresses of Entomology. There have also been eight international symposia on quality control (Bigler, 1991). Wajnberg and Hassan (1994) study critically examines and connects research from the mid-1970s because Trichogramma, the parasitoid world's Drosophila, has created a vast volume of material. The emphasis here is on how we have used this fundamental knowledge to develop effective field initiatives.

Applicability of Trichogramma

The majority of Trichogramma releases have occurred in the last 50 years; attempts before to 1975 were targeted at controlling lepidopterous pests in sugarcane and corn. Cotton, sugarbeet, vineyard, cabbage, plum, apple, woods, tomato, and rice pests were also addressed between 1975 and 1985. Numerous crops have been studied since 1985, and the list is expanding (Hassan, 1993).

Crop	**Target genera**	**Trichogramma species**
Corn	*Osrinia*	*brassicae*
		nubilale
		ostriniae
		evanescens
Cotton	*Cnephasia*	*evanescens*
	Ostrinia	*pretiosum*
	Helicoverpa	*pretiosum*
		confusum
Sugarcane	*Helicoverpa*	*pretiosum*
	Chilo	*evanescens*
	Chilotraea	*chilonis*
	Diatraea	*chilonis*
Tomato	*Helicoverpa*	*pretiosum*
	Trichoplusia	*pretiosum*
	Manduca	*pretiosum*
Rice	*Cnaphalocrocis*	*japonicum*
Cabbage	*Mamestra*	*evanescens*
	Pieris	*evanescens*
	Plutella	*evanescens*
Apple	*Cydia*	*dendrolimi*
	Adoxophyes	*embryophagum*
Forests	*Dendrolimus*	15 different species
Peanut	*Cadra*	*pretiosum*
	Plodia	*pretiosum*
Fruit	*Adoxophyes*	*dendrolimi*
Citrus	*Cryptophlebia*	*toidea cryptophlebiae*
Pomogranate	*Deudorix*	*chilonis pomegra*

Corn has received the most attention and has had the most consistent results. In crops such as cotton and rice, where, despite extensive study, the use of pesticides to treat numerous pest issues diminishes Trichogramma activity, inconsistent outcomes have been discovered (King *et al.*, 1986). Inundative releases for the control of lepidopterous pests are now being researched in over 50 countries and are reported to be employed commercially on over 32 million hectares per year. This acreage is overstated because some places in the former Soviet Union receive repeated applications (Filippov, 1990). Trichogramma are regarded as financially efficient in the former Soviet Union and China, and they compete well with pesticides for commercial control of corn borer in Europe, despite the fact that certain prices are subsidised (Newton, 1993). Eastern nations and certain Asian and South American countries have a longer history, but Australia and North and Central American countries have only lately begun to examine Trichogramma's possibilities (Ciochia, 1990). In North America, they find a niche in organically cultivated crops and locations where pesticide resistance has evolved. Despite the large number of crops and regions where inundative releases have occurred, only a few pest and Trichogramma species have been researched. The majority of trials have begun against the primary pests, *Ostrinia spp*. and *Helicoverpa zea*, with rare releases against different pyralids, tortricids, noctuids, oleuthrids, and pierids, in decreasing order. Even in the former Soviet Union, Trichogramma is only utilised to control roughly seven pest species (Gusev and Lebedev, 1988). The following Trichogramma species have been utilised in most studies, in decreasing order: *evanescens, dendrolimi, pretiosum, brassicae* (=*muidis*), and *nubilale*. Ten other species have been used occasionally. Because of their versatility in environment and host selection, the first three species have dominated the investigations in general. Although many publications mention commercial accomplishments, the majority of papers address specific scientific problems. To be commercially viable, all Trichogramma initiatives must handle four issues: the selection of the proper population to release, a mass rearing method, parasitoid dissemination, and a field release plan.

Selection of parasitoids based on interspecific and intraspecific variation to release

In selecting the best parasitoid for release, start with the best species. Since the genus has more than 145 species, there is considerable interspecific variation, and the taxonomy of the genus is still not fully understood (Pinto and Stouthammer, 1994). Various orders of insects, including Lepidoptera, Coleoptera, Diptera, Heteroptera, Hymenoptera, and Neuroptera, host the genus' polyphagous egg parasitoids. It has been observed, however, that species are becoming more specialized as they are discovered. Taxonomy of this genus may be clarified by recent molecular studies (Pintureau, 1993). In most cases, the local species is selected for release based on ecological considerations such as climate, habitat, and host conditions (Voegelt, 1988). It has been reported that at least six species of Trichogramma have been used in the control of Ostrinia species. Among their native species, *T. nubilale* and *T. pretiosum* most commonly occur in the United States, *T. ostriniae* and *T. dendrolimi* most commonly in China, and *T. evanescens* and *T. brassicae* (=maidis) most commonly in Europe. Inundative theory suggests the use of local species, which is contraindicated only if there is no native species, or if preintroduction screening indicates otherwise. There are different species of Trichogramma that compete with one another (Pak and Oatman, 1982). The introduction of non-native species into diverse habitats could lead to the extinction of local species or strains (Howarth, 1991). Before parasitoids are released, it is important to survey local species, since the natural level of parasitism can range from 40-100%. Recent actions taken by some countries to restrict the importation of organisms for biological control make it even more important to identify native species that are effective, especially during the first screening. Following the selection of a species, it is necessary to determine the population (= strain) to be released. Trichogramma exhibits both interspecific and intraspecific variations in biology and behaviour, which are heavily impacted by environmental variables. These variances further complicate the selection process, and various research have focused on phenotypic differences across strains (inter populations). The development, fertility, egg absorption, sex ratio, lifespan, host age selection, oviposition, host choice, and activity of these populations have been compared (Pak *et al.,* 1986), as well as their responsiveness to environmental variables (Pak, 1986). A few studies have also looked at the incidence of thelytokous (all female offspring) or deuterotokous (nearly all female offspring) populations, as well as their fitness or fertility in comparison to the more prevalent arrhenotokous (50-751 female children) strains (Stouthamer and Luck, 1993). The final strain will be chosen based on how it ranks in terms of biological characteristics considered favourable for the habitat into which it will be released, as well as the manner of release to be carried out (e.g., inundative or inoculative). The third part of selection is that of founding populations, or where and how many collections (both individuals and populations) are required to start a healthy colony. This is one of the least studied fields since it is reliant on population genetics, and nearly little is known about Trichogramma genetics. Several studies have investigated the genetic variability of traits such as reproductive capacity (Pintureau *et al.*, 1981), responsive distance, walking behaviour (Limburg and pak, 1991), and sex allocation, however the genetic basis for biological differences between or within populations (intra populations) has received little attention. Traditional knowledge recommends that a minimum of 500-1000 individuals should be utilised to establish a population with high levels of heterozygozity; this strategy was applied in the former USSR. Trichogramma are haplodiploid organisms (most females develop from fertilised diploid eggs, while most males develop from unfertilized haploid eggs), with high rates of sib-mating and inherently low heterozygozity. This characteristic shows that the degree of heterozygosity generally necessary to establish a strong Trichogramma species colony may be less than predicted, and that healthy colonies can be created with less than 500 individuals.

Selection of parasitoids based on Parasitoid Quality

Population variation enables for the selection of high-quality parasitoids. Populations for inundative release are frequently chosen based on high fertility, emergence, sex ratio (% of female progeny), life-span, host choice for the target species, host-searching activity, and adaptability to local weather conditions. Because these qualities are thought to be ecologically relevant for these parasitoids when distributed inundatively, a population with these characteristics is described as a parasitoid of "high quality." Characteristics like as development rate, oogenesis, and competitive ability are also significant for those employed in inoculative releases. Regrettably, one variant is rarely outstanding in all aspects, and it is sometimes uncertain if high-quality variants in the laboratory are equivalent with efficient parasitoids in the field. Furthermore, some of the characteristics that make the parasitoid efficient in the field may not be useful in mass rearing (e.g., those that prefer the target species may be more difficult or impossible to raise on a factitious host), therefore trade-offs in terms of the desirable qualities must be made (Lenteren, 1991). Numerous authors have examined individual components of quality, including fecundity (Bai *et al.*, 1995), development rate, oogenesis (Tavares and Voegelt, 1990), emergence, sex ratio, longevity, host acceptance and preference, host searching and activity, and the effect of the environment.

System for mass rearing production of host as well as parasitoid

Host rearing

The species to utilise (including artificial host eggs) and whether the eggs may be kept to extend the facility's production period are two significant biological considerations of host rearing. Until now, the option in host rearing has been confined to species that produce either tiny or big eggs. Flanders provided a little host egg, the Angoumois grain moth, *Sitotroga cerealella*, which is now used by growers in slightly more than half of the world. Because of improved productivity from the rearing medium, ease of automation, and improved sanitation conditions, some nations, notably France and Canada, have shifted to the Mediterranean flour moth, *Ephestia kuehniella*. The rice meal moth, *Corcyra cephalonica*, is the third tiny egg species employed in several Asian nations due to its local availability. There have been no studies that compare parasitoids produced from Corcyra to parasitoids grown from other tiny egg species. However, repeated tests have demonstrated that Trichogramma growing from either Ephestia or Sitotroga are field comparable. Ephestia parasitoids have shown slightly greater performance in the laboratory, presumably because to their slightly bigger size (Bigler *et al.*, 1987). Trichogramma has been reared using four major host egg species of Lepidoptera, three of which are from China. Silkworm hosts are regarded commercially feasible since their eggs are a byproduct of silk manufacturing, but *Ostrinia nubilule* has largely been employed for research (Burbutis and Koepke, 1981). Trichogramma wasps raised on large host eggs may be of greater quality (larger size and higher percentage of females) than those raised on tiny host eggs. As a result, facilities can generate either a large number of little (low-quality) parasitoids or a limited number of large (high-quality) parasitoids on a continuous basis. Despite the potential for higher parasitoid quality, the practicality of utilising species that deposit big host eggs in commercial production has not yet been compared to that of species that lay tiny host eggs. In vitro production on artificial host media is a relatively new technique in Trichogramma rearing (Grenier, 1994). Since 1975, China has been doing research in this field. There have been two methods. The native insect egg hemolymph is partially replaced with egg yolk and milk solids in the first technique. The second strategy involves creating a wholly artificial diet based on biochemical analyses of the insect and its egg (Nettles *et al.*, 1985). In various kinds of artificial medium, eighteen Trichogramma species have already been raised from egg to adult. The closest technique to commercial production was established in China for *T. dendrolimi* using insect hemolymph. This diet was packaged in plastic host egg-cards (made at a rate of 1200 egg-cards per hour), and the parasitoids produced were deployed over more than 1300 hectares with parasitism equivalent to parasitoids produced from natural host eggs (Dai *et al.*, 1990). The creation of totally artificial hosts is an essential aim that, if completed, would result in significant reductions in facility size, product cost, and modifications in field application approach.

Parasitoid rearing

To assure good product quality and minimise contamination, facilities typically raise only a few parasitoid strains or species at any given time (Gusev and Lebedev, 1988). Improved approaches for rapidly identifying various populations using DNA markers are being developed, and their incorporation into facilities may aid in screening for such rearing issues (Sappal *et al.*, 1995). The ratio of parasitoids to host eggs in parasitization units is also significant. High ratios can result in superparasitism, a large number of male offspring, and poor product quality, whereas low ratios can result in poor parasitization and wasteful utilisation of host eggs. Trichogramma accepts and allocates offspring in host eggs based on host density, and parasitoid fecundity or clutch size is regulated based on host availability relative to abundance (Fleury and Boulttreau, 1993), host egg size (Schmidt and Smith, 1987), and spacing between eggs (Schmidt and Smith, 1985). Once consistent parasitism of host eggs has been accomplished by light and temperature manipulation, their emergence must be controlled. Programming can be as basic as permitting the parasitoids to grow at a specific temperature and photoperiod or as sophisticated as manipulating environmental parameters to accomplish synchronisation, long-term storage, and delayed emergence. In general, keeping at low temperatures (6-12°C) during the pupal stage is preferred for Trichogramma (Jalali and singh, 1992), though such storage has never been continued for more than two weeks without parasitoid quality losses (Vieira and Tavares, 1995). Species that are more cold resistant, such as *T. brussicue* (=maidis), ostriniue, evunescens, and dendrolimi, and/or go through diapause (caused by temperature and photoperiod effects on the maternal generation and developing larvae, as well as probable host egg impacts), may withstand extended storage (Boivin, 1994, Laing and Corrigan, 1995). The particular circumstances that enhance parasitoid storage and diapause are being aggressively explored in order to allow rearing facilities to save money and improve the genetic quality of their stock. Superparasitism and intrinsic competition are two further elements that may influence the spread of emergence. The preservation of parasitoid quality is crucial to a manufacturing facility's reputation, and the quality may be jeopardised after maintaining Trichogramma for many generations under consistent circumstances and on an uncommon host. Loss of tolerance to natural physical extremes and loss of predilection for the target host are two significant alterations that can occur. The initial modification has received little attention, despite the fact that raising the parasitoid in temperature fluctuations is indicated to preserve tolerance. Unfortunately, in a commercial raising facility, this proposal is difficult to implement. The loss of preference for the target host is a controversial subject, since it has been established for some Trichogramma species but not for others. Approaches used to counteract this impact include limiting the number of generations that may be reared in the facility, moving the parasitoids to various hosts on a regular basis, or both. In France, 100 female *T. brussicue* are gathered annually and maintained in isofemale lines for three generations before being combined together for a maximum of 20-25 generations. *T. brussicue* is raised on Ephestia for a maximum of six generations in Switzerland; if kept longer, it is moved to the target host. This switching to the target or any fictitious host is likewise suggested in Germany, Australia, and the former USSR, though parasitization issues might arise during the first generation.

Timing, frequency, and rates of release

The technique used determines the time, frequency, and rate of release. With inoculative releases, just a few parasitoids are needed early in the season, perhaps irrespective of the pest's ovipositional phase. In contrast, inundative releases necessitate enormous numbers that are tightly timed with the initiation of oviposition of a uni- or bivoltine pest (Smith, 1994). The earlier oviposition can be anticipated, the better it is for the raising facility and the field programme. If a significant quantity of parasitoids are required quickly, certain facilities may demand many weeks or months' notice. To synchronise inundative releases with the onset of host oviposition, several approaches such as calendar date, plant growth, pheromone or light traps, egg-laying, and developmental degree-days have been utilised. Unless it is tied to pest phenology, plant development is the least reliable technique (Burbutis and Koepke, 1981). Although it is currently too variable to be utilised alone, the degree-days technique provides for the most accurate forecasting (about one month); this method has the potential to be the most helpful (Neil *et al.,* 1990). Because they gather adult moths before oviposition, light traps (Bigler and Brunetti, 1986) and, when accessible, pheromone traps (Maini *et al.,* 1988) appear to be the best predictors (especially pheromone traps). Comparing trap capture, oviposition, and effectiveness has repeatedly revealed that the best outcomes are obtained when the Trichogramma are released a few days before, rather than at the beginning of, oviposition (Kanour and Burbutis, 1984). Synchronization with the host also implies that parasitoid emergence must be programmed. Although most facilities export parasitoid material that is ready to emerge and the majority of releases employ material that emerges within hours of release, this is not always the case. Some critical tactics combine multiple stages of Trichogramma growth, delaying emergence, especially if only one or a few releases are possible. This strategy assures that certain females are constantly actively searching during host oviposition. In practise, this method is restricted if the released eggs are preyed upon or subjected to high temperatures. The first release is frequently timed immediately before host oviposition in order to produce high levels of parasitism while also allowing released material to proliferate in natural host eggs. This method assures that a steady supply of high-quality parasitoids is generated from the target pest in the field.

Eficacy of releases

Various simulation methodologies have been employed over the last 50 years to increase the efficacy of Trichogramma releases. The majority of these techniques have focused on the timing or quantity of parasitoids required to reduce host density (Goodenough and Witz, 1985, Knipling and McGuire, 1968), parasitoid seeking area, and disappearance rate. Regarding the pest's population dynamics. Two more models have been created to predict host population damage (Witz *et al.*, 1985) as well as searching efficiency and parasitism in relation to the field. Models for application rates and timing imply the following: 1. more than 80% parasitism is required to diminish pest populations; 2. the rate of release increases proportionately with leaf surface area and disappearance rate; and 3. the rate can be lowered in half if parasitoids emerge at different times (Smith and You, 1990). The majority of these predictions have been confirmed by field research. Simulation models deserve much more improvement because they have all boosted our comprehension and pointed to areas that require more study focus. The heterogeneity with which Trichogramma releases are recorded is one of the problems in measuring their efficacy, as does the variable with which application rates are reported. Some studies merely mention parasitism, whereas others mention larval populations, infection levels, and product weight or volume. Furthermore, some papers simply discuss differences in these levels between control and treated regions, increases in parasitism and product, or decreases in pest, infestation, or damage. A major issue in several research is the use of insecticide-treated plots as "control" plots. True, untreated controls are never utilised in other investigations (Zhou, 1988). When the target host produces eggs in clusters (e.g., Ostrinia, Choristoneura, and Dendrolimus), reports of parasitism without mention to the cluster exist. Bin and Vinson, 1990 provide a compelling case for standardising nomenclature in reporting parasitism. Most studies evaluate effectiveness by quantifying egg parasitism, often of eggs deposited in the field by the target host. However, unless these collections are collected towards the conclusion of oviposition after enough time has passed for all parasitized eggs to be detected (e.g., become black), this strategy may underestimate parasitism. One solution is to post sentinel eggs (e.g., factitious or target host eggs on cards) of known age in the field for a certain period of time. This method measures daily parasitism, but new research reveals that it may potentially underestimate parasitism, especially if the monitor eggs are more appealing than normal host eggs. This issue highlights the importance of compensating for this disparity before final evaluation.

Future prospects and needs

Trichogramma usage has advanced significantly in the last 50 years, which speaks well for the coming decades. Significant commercial gains have been realised with Trichogramma, as with Bt and chemical pesticides, wherever strong scientific attention has been directed (e.g., corn borer control). These accomplishments imply that we have a good probability of succeeding in additional undiscovered host/parasitoid systems. The taxonomy of this genus is currently being worked out. This study is critical since it serves as the foundation for further investigations. Although much information on phenotypic diversity is accessible, additional work has to be done on its genotypic basis to assess if the selection of a super strain is conceivable. Similarly, despite the fact that we have generated a vast quantity of data on parasitoid biology and behaviour, we now need to compress this data into some cohesive, standardised idea of parasitoid quality with proper prediction methods. Although large-scale commercialization of raising facilities has occurred, there is still a need to investigate various rearing hosts and artificial diets in automated systems in order to make significant progress. One of the most significant areas in the future will be the development of extension support to offer the product to the user and allow them to enter the field in a way that has an impact. The product should offer instructions on where, when, and how to release it in various grower scenarios. This package, which will offer a service rather than just a commodity, might come from the producers, government extension, or private consultation. In the past, skilled professionals who provided this mix of biology and economic decision making yielded the best outcomes with Trichogramma. Stinner (1987) finished his assessment by emphasising the need of combining Trichogramma with other control strategies. The situation is no different now, except that we now have a better understanding of how to accomplish this integration. Trichogramma has been used as a substitute for chemical pesticides much too often in the past. Inoculative releases must be created in conjunction with specific insecticides (chemical or biological), other parasitoids, and nectariferous plants such as refugia. Although Trichogramma release is presently one of the most benign pest management methods, greater attention must be made to the pest's population dynamics, other natural mortality mechanisms at work, and the native complex of natural enemies, particularly native Trichogramma species. This method will ensure a better knowledge of the impact of pest release on biodiversity and a less disruptive approach to pest management.

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TERMINAL HEAT STRESS: CURRENTLY A MAJOR ISSUE AFFECTING FIELD CROPS SUSTAINABILITY

Mehak Nagora*[1], Sharad Nagora[1], Lalit Kumar[2], Pardeep Kumar[1] and Renu[3]

[1]Department of Agronomy, College of Agriculture,

[2]Department of Genetics and Plant Breeding

[3]Department of Agrometeorology

CCS Haryana Agricultural University, Hisar-125004, Haryana

*Coreesponding author E-mail: mehaknagora4@gmail.com

Abstract:

In India, for instance, the Green Revolution has significantly increased food grain output. Since the middle of the 1990s, cereals output has typically exceeded domestic demand, leading to a rise in grain exports. In the previous fifty years, rice yield increased by 145 % and wheat output by 270 %. Despite these achievements, agricultural labour productivity remains less than a third of that in China and less than 1% of that in frontier nations. However, there is mounting evidence that yield increase has plateaued and there is a risk of future yield losses due to global climate change and unsustainable food production techniques in light of environmental degradation. Stress is currently one of the greatest hazards to agriculture. Stresses induce a vast array of plant responses, including changes in gene expression, cellular metabolism, growth rates and crop yields. Plants are exposed to two types of environmental stressors, which may be characterised as biotic and abiotic stress. Abiotic stress such as drought, waterlogging, severe temperatures (cold, frost, heat), salt and mineral toxicity significantly effect plant growth, development, yield and seed quality. Terminal Heat Stress (high temperature stress), an element of the physical environment, is one of the most significant factors restricting crop productivity throughout the globe. Therefore, the heat stress tolerance mechanism is essential for establishing an effective strategy for managing yield levels under conditions of heat stress and climate change. To produce heat-tolerant, high-yielding crops, it is necessary to comprehend the metabolic and developmental processes connected with heat stress and energy control. There is still a need for a deeper knowledge of the biochemical and molecular foundation of heat tolerance in order to increase crop yields in future warmer settings. It is vital to emphasise that molecular research confirms an increase in commercial crop production, but crop-level yield assessment is necessary for the full manifestation of yield potential.

Keywords: Climate change, green revolution, molecular, unsustainable and yield potential.

Introduction:

The developing world has undergone an exceptional era of food crop production rise during the past 50 years. Although populations had more than quadrupled, cereal crop output tripled over this time period despite just a 30% increase in cultivated land area. The Green Revolution was characterised by the introduction of high yielding variety (HYV) seeds, the widespread use of fertilisers, herbicides and insecticides and the expansion of irrigation.

In India, for instance, the Green Revolution has significantly increased food grain output. Since the middle of the 1990s, cereals output has typically exceeded domestic demand, leading to a rise in grain exports. In the previous fifty years, rice yield increased by 145 % and wheat output by 270 %. Despite these achievements, agricultural labour productivity remains less than a third of that in China and less than 1% of that in frontier nations.

However, there is mounting evidence that yield increase has plateaued and there is a risk of future yield losses due to global climate change and unsustainable food production techniques in light of environmental degradation. Stress is currently one of the greatest hazards to agriculture. Stress in plants refers to environmental factors that inhibit plant growth, development or output. Stresses induce a vast array of plant responses, including changes in gene expression, cellular metabolism, growth rates and crop yields.

Typically, a plant stress is the result of abrupt changes in environmental conditions. Agricultural crops are exposed to a variety of environmental factors that degrade and restrict their yield.

Plants are exposed to two types of environmental stressors, which may be characterised as shown in Figure 1.

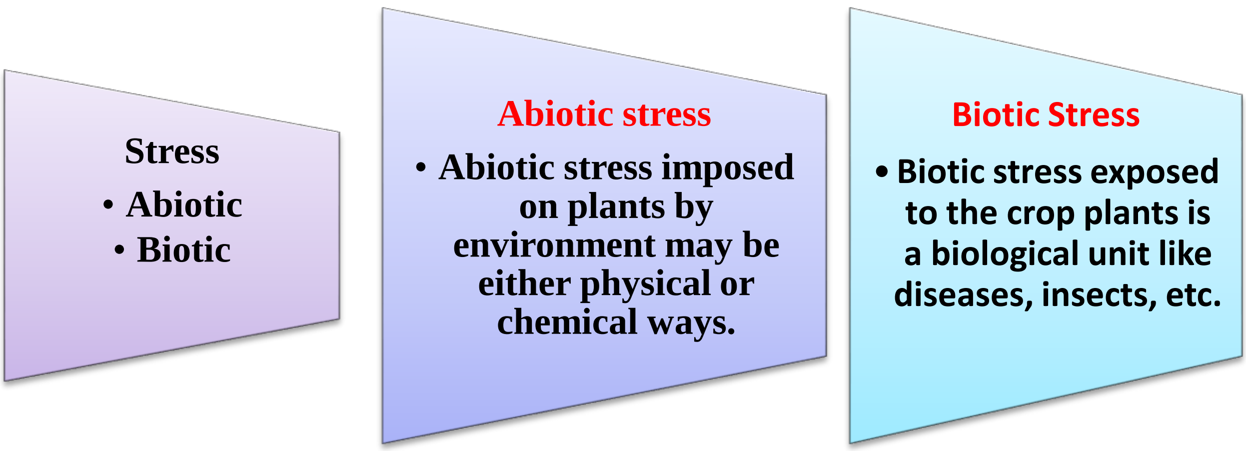


Figure 1: Types of stress affecting crop yield

Living organisms, particularly viruses, bacteria, fungus, nematodes, insects, arachnids and weeds, induce biotic stress in plants. The agents that cause biotic stress directly deplete their host of nutrients, which can result in the demise of plants. Due to pre and post-harvesting losses, biotic stress can become severe.

The biotic stress is totally different from abiotic stress, which is imposed on plants by non-living factors such as salinity, sunlight, temperature, cold, floods and drought having negative impact on crop plants. It is the climate in which the crop lives that decides what type of biotic stress may be imposed on crop plants and also the ability of the crop species to resist that particular type of stress. Many biotic stresses affect photosynthesis, as chewing insects reduce leaf area and virus infections reduce the rate of photosynthesis per leaf area.

On the other hand, Abiotic stress such as drought, waterlogging, severe temperatures (cold, frost, heat), salt and mineral toxicity significantly effect plant growth, development, yield and seed quality. Future abiotic stress will likely intensify. To maintain food security and safety in the next years, it's urgent to produce abiotic stress-resistant crop cultivars. A plant's roots defend it against abiotic stress. Healthy, biologically varied soil helps plants survive adverse situations. Abiotic stressors influence plant production globally. Interconnected abiotic challenges include osmotic stress, ion distribution problems and plant cell homeostasis. Changes in gene expression impact growth and productivity. Identifying abiotic stress-responsive genes is crucial to understand agricultural plant stress response processes. Figure 2.
plant stressors.

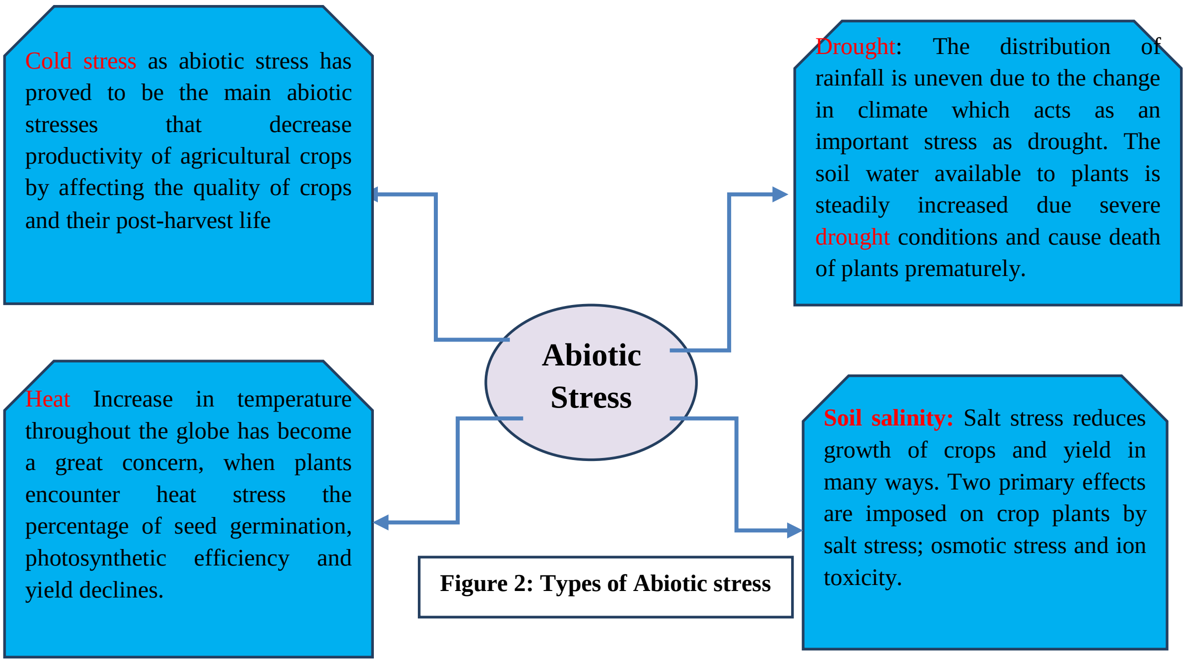


Figure 2: Types of Abiotic stress

Terminal Heat Stress (high temperature stress), an element of the physical environment, is one of the most significant factors restricting crop productivity throughout the globe. Since the turn of the century, ambient temperatures have increased and it is anticipated that this trend will continue due to climate change. This temperature increase can induce heat stress, especially if it happens during the reproductive and grain filling periods (Farooq *et al*., 2011). The question now is, what is meant by terminal heat stress?

Definition:

High temperature after anthesis is known as terminal heat stress, and continuous stress is encountered when the average daily temperature in the season's coldest month surpasses 17.5 °C. Heat stress is a result of the amount, pace, and duration of exposure to elevated temperatures (Wahid *et al*., 2007). Continuous heat stress affects roughly 7.0 million hectares of wheat in developing nations, but terminal heat stress affects around 36.0 million hectares in 40 % of the temperate environment, and the significance of high temperature stress is projected to expand in the coming years (Reynolds *et al*., 2001). The duration of the grain filling phase, kernel size, biomass and the number of tillers are all reduced by heat stress, which has a negative effect on crop yield, especially wheat. In the current, 2020, and 2050 scenarios, simulations indicate that terminal heat stress will lower wheat output by 18.1 per cent, 16.1 per cent and 11.1 per cent, respectively (Dubey *et al*., 2020).

Plant Response to terminal Heat Stress:

As sessile creatures, plants cannot shift to more favourable habitats in response to abiotic or biotic challenges; as a result, plant growth, development and production are significantly impacted (Lippmann *et al*., 2019). In recent decades, global warming has exacerbated the rise in air temperature, which is a significant stressor (Hedhly *et al*., 2009). Consequently, the methods by which plants adapt to high temperatures are of considerable importance (Figure 3). Plants subjected to high temperatures (heat stress, HS) have severe and occasionally fatal negative consequences. Plants have evolved complex systems to respond to HS in order to survive in such environments. Several fundamental physiological activities of plants, like as photosynthesis, respiration and water metabolism, are responsive to HS (Liu *et al*., 2020).

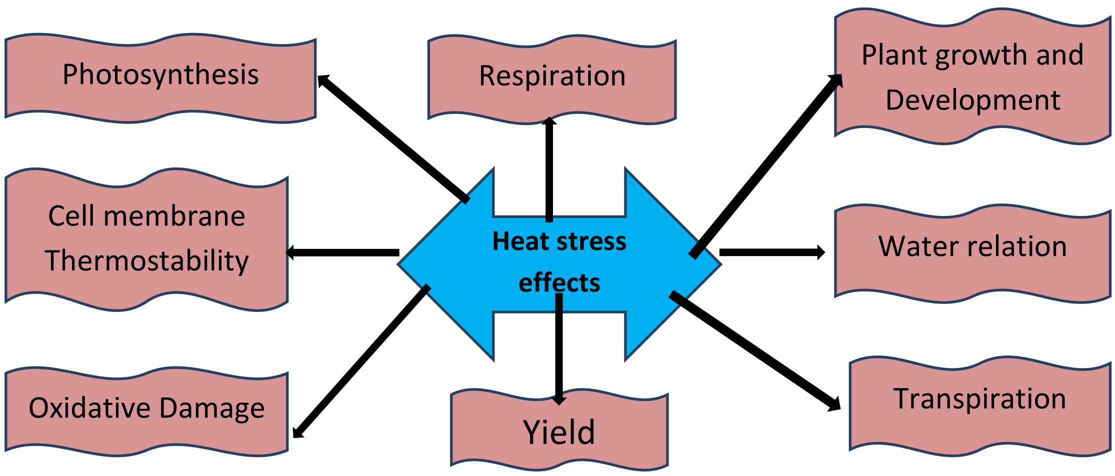


Figure 3: Agro-physiological effects of Heat Stress

Adverse effect of Heat stress as follows:

Growth and Development: Among plant growth phases, germination is the first to be impacted. During seed germination, several crops are negatively impacted by heat stress. Reductions in germination rate, plant emergence, aberrant seedlings, seedling vigour and radicle and plumule development of geminated seedlings have been identified as prominent effects of heat stress in several cultivated plant species. At extremely high temperatures (45 °C), the germination rate of wheat was strongly inhibited and cell death and embryo mortality occurred, resulting in a decreased seedling establishment rate. Rice cultivar's plant height, number of tillers and total biomass decreased in response to HT. Lower net assimilation rate (NAR) is an additional factor contributing to the reduced relative growth rate (RGR) under HT. The morphological indications of heat stress include scorching and sunburning of leaves, twigs, branches and stems, leaf senescence and abscission, suppression of shoot and root development and discoloration and damage to fruits. Due to HT stress, damage to the leaf tips and margins, leaf rolling and drying and necrosis were seen in plants.

Reproductive Development: Although all plant tissues are susceptible to heat stress at nearly all phases of growth and development, reproductive tissues are the most sensitive and a few degree temperature increase during blooming can result in the loss of whole grain crop cycles. During reproduction, a brief period of heat stress can induce a considerable drop in floral buds and flower abortion, despite the fact that plant species and varieties vary greatly in their sensitivity. Even throughout the reproductive stages of a plant's growth, the plant may not generate blooms and blossoms may not yield fruit or seeds. Impaired meiosis in both male and female organs, impaired pollen germination and pollen tube growth, reduced ovule viability, anomaly in stigmatic and style positions, reduced number of pollen grains retained by the stigma, disturbed fertilisation processes and obstruction in growth of the endosperm, proembryo and unfertilized embryo are the causes of increasing sterility under abiotic stress conditions including the HT.

Water relations: Changing ambient temperature is often found to have the greatest effect on the water status of plants. High temperature appears to produce dehydration in plant tissue, which therefore inhibits plant growth and development. During blooming, 31 °C is widely regarded as the top limit for preserving a crop's hydration condition (Atkinson and Urwin, 2012). With a corresponding increase in leaf temperature, heat-stressed wheat plants significantly lower leaf water potential and relative water content, subsequently reducing photosynthetic efficiency (Farooq *et al*. 2009). Simultaneously, both the transpiration rate and the rate of plant development are drastically altered. Heat stress also enhances the hydraulic conductivity of cell membranes and plant tissues, mostly because of enhanced aquaporin activity (Martinez-Ballesta *et al*., 2009) and to a higher degree because of decreased water viscosity (Cochard *et al*. 2007).

Transpiration: Due to decreased root nutrient uptake, lower root biomass and metabolic rate or direct root injury, as well as a drop in transpiration rate caused by a water shortage, the plant's response to high temperature may also impair nutrient absorption and the efficiency of their usage.

Yield: Temperature increases are causing anxiety over agricultural yield and food security. Even a minor (1.5 °C) rise in temperature has major detrimental impacts on crop production under its influence. Higher temperatures primarily impact grain production by altering phenological development processes. Numerous cultivated crops, such as cereals (e.g., rice, wheat, barley, sorghum, maize), pulses (e.g., chickpea, cowpea), oil-yielding crops (mustard, canola) and so on, have been reported to experience heat-induced yield decrease. It was proven that a rise of 1 °C in the seasonal average temperature lowered wheat grain output by 4.1 % to 10 %. (Wang *et al*., 2012). The sensitive crop types are impacted by heat stress more strongly than the tolerant kinds.

Oxidative damage: The formation of oxidative stress-inducing ROS, such as singlet oxygen, superoxide radical, hydrogen peroxide and hydroxyl radical, in plants subjected to heat stress is common. In several plants, including wheat, oxidative stress significantly enhanced membrane peroxidation and lowered membrane thermostability. Hydroxyl radicals react with nearly all cellular components. Continuous heat stress in plants may result in build-up of reactive oxygen species (ROS) in the plasma membrane of the cell, depolarization of the cell membrane, activation of the ROS-producing enzyme RBOHD and initiation of programmed cell death. However, plants possess antioxidant systems that allow them to escape excess ROS.

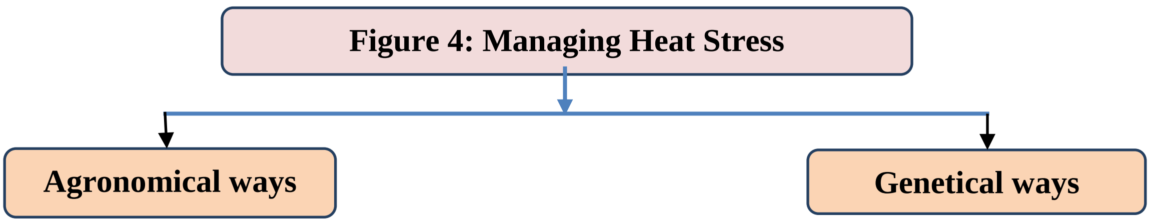
Cell membrane stability (CMS): is one of the sub traits used to evaluate drought and heat stress and select resistant genotypes. Both drought and heat stress have a detrimental effect on the selective permeability of the plasma membrane of plant cells. Therefore, the cell is unable to preserve its internal makeup. The injury impairs plant development and growth. The damage to the cell membrane induced by drought and heat under field circumstances was estimated by measuring the solute leakage from plant tissue. Using chemical desiccants such as polyethylene glycol, plant sensitivity to water deficiency was screened (PEG). It has been demonstrated that PEG may be used to alter the water potential of solutions, so creating potential osmotic pressure, which can be employed as a drought stress mediator. Consequently, a number of studies utilised the effect of PEG on the CMS as an initial step in selecting the most promising drought- and stress-tolerant genotypes. Similarly, the effect of heat stress on the thermal stability of cell membranes was examined in the field and in vitro. Overall, it was determined that cell membrane stability is a quantitative property that is moderately heritable, has a strong genetic association with grain yield and that a small number of genes govern the majority of the variance in cell membrane permeability.

Photosynthesis: Photosynthesis transforms light energy into chemical energy for plant development and growth. As the most complex physiological activity in plants, photosynthesis consists of several subsystems, including CO_2 reduction routes, photosynthetic photosystems and the electron transport system. Photosystem II (PSII) has been described as the component of the photosynthetic machinery that is most sensitive to heat. Heat stress causes a decrease in PSII abundance and an increase in Photosystem I (PSI) in *Populus euphratica*. It also generates photosynthetic linear electron flow (Ferreira *et al*., 2006). Additionally, moderate heat stress reduces Rubisco activity. The side reaction of Rubisco oxygenase stimulates the generation of H_2O_2, which is harmful to plant cells. High temperature has a bigger effect on the photosynthetic capability of plants, particularly C_3 plants, than it does on C_4 plants.

Carbon metabolism in the stroma and photochemical processes in the thylakoid lamellae are regarded to be the principal sources of damage at HTs in chloroplasts. The thylakoid membrane is extremely vulnerable to HT. Under heat stress, chloroplasts undergo significant changes, including altered structural organisation of thylakoids, loss of grana stacking, and grana swelling. Under HTs, photosystem II (PSII) activity is significantly inhibited or even ceases. The quantity of photosynthetic pigments is reduced by thermal shock. Heat tolerance is directly proportional to a plant's capacity to maintain leaf gas exchange and CO_2 assimilation rates under conditions of heat stress. The leaf water status, leaf stomatal conductance, and intercellular CO_2 concentration are significantly altered by heat. Under HT, the closure of stomata contributes to the impairment of photosynthesis, which impacts intercellular CO_2.

Respiration: Heat stress modifies mitochondrial functions via altering respiration. The rate of respiration increases with rising temperature, but below a particular threshold, it decreases owing to respiratory apparatus injury (Prasad *et al*. 2008). The increased rate of respiratory carbon loss caused by heat stress in the rhizosphere decreased ATP synthesis and increased ROS production (Huang *et al*. 2012). Because heat stress influences the solubility of CO_2 and O_2 and the kinetics of Rubisco, this is the case (Cossani and Reynolds, 2012). Almeselmani *et al*. (2012) found that the rate of respiration in the flag leaf of wheat was considerably greater in heat-susceptible varieties under heat stress (35/25 °C Day/night) than in the control group (23/18 °C Day/night).

Ways of Managing Heat Stress: There are different ways of managing heat stress as represented in Figure 4.



Let's discuss all these one by one.

Agronomical management: Adoption of various agronomic practices like

1. Water conserve techniques
2. The appropriate amount and methods of fertilization
3. Maintaining proper time and methods of sowing
4. The application of exogenous protectants can effectively alleviate the adverse impact of heat stress in wheat.

Conserving soil moisture: A continual water supply is required for agricultural plants to maintain their grain-filling rate, duration, and grain size. Mulching may be the greatest method for maintaining optimal soil moisture and temperature regimes. Straw mulch prevents soil evaporation, so conserving soil moisture. However, mulching is recommended to prevent yield loss when decreased tillage is employed. It has been observed elsewhere that in conditions of extreme heat and water deficiency, mulch can increase crop yield. The use of organic mulches protects greater soil moisture and enhances plant growth and development, which may lower water and nitrogen consumption efficiency. This approach has been demonstrated to be highly beneficial in temperate and tropical countries with unfavourable heat stress conditions for wheat production.

Nutrient management: Temperature-stressed plants require an adequate and well-balanced mineral nutrition supply. Post-anthesis applications of nitrogen, phosphorus, and potassium increase grain proteins while day and night temperatures stay at 24 and 17 °C, respectively, but have little impact at higher temperatures. Nutrient foliar sprays are highly effective and can mitigate the negative effects of heat stress on wheat. Potassium orthophosphate used as a foliar spray after anthesis might be an alternate method for increasing wheat's heat tolerance. Potassium orthophosphate delays leaf senescence produced by heat stress and increases grain production.

Planting time: A change in planting technique might mitigate the negative effects of heat stress during the reproductive phase of wheat. Permanent bed planting under zero-tillage with crop residue retention has been suggested as a feasible method for enhancing agricultural plants' heat tolerance. Planting under conventional tillage with straw mulch boosted soil water-holding capacity, organic carbon and total nitrogen, hence mitigating the high temperature-induced decline in grain weight during the late grain filling stage.

Use of exogenous protectants: In recent years, exogenously applied growth-promoting protectants, such as osmoprotectants, phytohormones, signalling molecules and trace elements, have resulted in the capacity to protect plants by neutralising the negative and detrimental impacts of heat stress. The use of these chemicals exogenously improves the thermotolerance of wheat under heat stress by reducing reactive oxygen species (ROS) and increasing antioxidant capacity. Several protectants, such as arginine, putrescine and tocopherol (vitamin E), have already proved their functions in thermotolerance when applied to thermosensitive wheat plants. External application of these molecules has ameliorating effects on oxidative stress by activating various enzymatic antioxidants, such as superoxide dismutase, catalase, ascorbate peroxidase and glutathione reductase and non-enzymatic antioxidants, such as ascorbic acid, tocopherol and glutathione. The widely used plant bio-regulators in horticulture crops have the potential to be employed in field crops, such as wheat and their possibilities are being highlighted as an emerging technique for relieving stress in a heat stress setting. Several naturally occurring intracellular polyamines (PAs), including as spermine, spermidine and putrescine, can play crucial roles for sustainable crop production under abiotic stress conditions. Recently, research into polyamine production, catabolism, and its function in abiotic stress tolerance has gained importance.

Bacterial seed treatment: Varietal improvement through the breeding program is time consuming and costly and gene transformation technology is not properly appreciated by many stakeholders. Therefore, utilizing biological control agents like fungus and bacteria are increasingly suggested as an alternate technique of boosting heat tolerance. Plant growth-promoting rhizobacteria are discovered to be compatible and having a good influence on the development of plants under heat stress. Seed treatment with rhizobacteria and foliar spray of several organic and inorganic chemicals boosted heat tolerance in wheat. Seed inoculation with rhizobacteria also dramatically increased heat tolerance in wheat. Seed treatment with *Bacillus amyloliquefaciens* UCMB5113 and *Azospirillum brasilense* NO40 strains were also reported to be helpful to boost heat tolerance of wheat seedlings by lowering ROS production.

Genetic management: Breeding is the response of plants to a changing environment. It necessitates the appraisal of genetic variety for adaptability to future climate change circumstances and, consequently, the selection and induction of stress-inducible genes from genetic resources for the development of novel varieties in production systems. Breeding for heat tolerance is still in its infancy, thus there is a great deal of focus on the genetic improvement of wheat to heat stress. In recent years, several investigations have been conducted to identify heat-tolerant wheat genotypes.

Screening and breeding for heat tolerance: In Australia and a number of developing nations, several physiological techniques have been proven to be helpful in breeding programmes. The process comprises scanning genetic resources to identify genetic grounds for crop heat tolerance. Following the physiologic crossing of novel trait combinations, desired new plant kinds can be generated to withstand future climates with high temperature occurrences. It is challenging to screen wheat genotypes under natural heat stress conditions in varied spatial settings. Therefore, no consistent selection criterion for evaluating various genetic materials for resistance to heat stress has been created. In general, selection criteria and screening procedures for selecting improved genetic materials resistant to heat stress are based on traits linked with greater grain production under unfavourable heat stress conditions. In this context, researchers proposed indirect selection criteria for improving wheat's heat tolerance.

Biotechnological approach for improving heat tolerance: By increasing heat tolerance, genetic engineering and transgenic techniques can reduce the negative impacts of heat stress. It involves the integration of desirable genes into the intended plants to increase heat tolerance. However, the intricacy of wheat's genomic structure makes genetic modification studies challenging. Long-term heat stress raises the protein synthesis elongation factor (EF-Tu) in wheat chloroplasts, which is connected with heat tolerance. The constitutive expression of EF-Tu in transgenic wheat protected leaf proteins from thermal aggregation, decreased thylakoid membrane disruption, increased photosynthetic capacity, and resisted pathogen invasion. Recently, several transcription factors (TFs) involved in diverse abiotic stressors have been identified and modified to increase crop stress tolerance. Recently, genome sequences of several plants have been developed for the enhancement of stress tolerance. They utilised very affordable sequencing technology and predicted that researchers will employ the presented methodologies to sequence various types of wheat. This will result in large-scale structural changes, which are known to play a significant role in the adaptation of wheat to various stressful conditions.

Conclusions and future perspective:

In the recent past, it was discovered that heat stress led to a worldwide decline in yield. Although extensive research has been conducted on the harmful effects of heat stress on wheat, the mechanism of heat resistance remains obscure. Therefore, the heat stress tolerance mechanism is essential for establishing an effective strategy for managing yield levels under conditions of heat stress and climate change. To produce heat-tolerant, high-yielding crops, it is necessary to comprehend the metabolic and developmental processes connected with heat stress and energy control. Although much progress has been made in understanding the effects of heat stress on wheat, there is still a need for a deeper knowledge of the biochemical and molecular foundation of heat tolerance in order to increase crop yields in future warmer settings. It is necessary to research the molecular understanding of response and tolerance mechanisms in order to achieve sustainable grain yields. To acknowledge this, the functional genomics method would be beneficial to the wheat's response to heat stress. It is well-established that classical and contemporary molecular genetics technologies, when linked with agronomic management approaches, may overcome the intricacy of the heat syndrome. To investigate the real impact of heat stress on ultimate crop production, many biochemical and molecular methods and agronomic strategies are necessary. In addition, the exogenous applications of protectants have demonstrated positive impacts on the enhancement of heat tolerance. The use of microorganisms to mitigate the detrimental effects of heat stress appears to be a valuable agricultural strategy. In light of anticipated global warming, it is believed that understanding the molecular foundation and tolerance mechanism may pave the way for creating plants that can survive heat stress and provide a good yield. In spite of the prospect of using EF-Tu to the development of heat-tolerant and disease-resistant wheat varieties by manipulating its expression levels, further research is required to determine the mechanism of action of wheat EF-Tu in relation to heat tolerance. It is vital to emphasise that molecular research confirms an increase in commercial crop production, but crop-level yield assessment is necessary for the full manifestation of yield potential. Therefore, crop modelling system studies are essential for enhancing wheat's heat stress tolerance and grain output.

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A REVIEW ON FACTORS AFFECTING ADSORPTION OF CARBOFURAN PESTICIDE IN SOILS

Nisha Sharma
Department of Chemistry,
Himachal Pradesh University, Shimla -171005, INDIA
*Corresponding author E-mail: nishasharma581@gmail.com

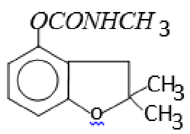
Abstract:

Increase in food production is the prime objective, to fulfill the demands of ever growing population. The consumption of pesticides has increased manifold, particularly during the past two decades due to their tremendous benefits. When pesticides are used properly they act as drugs/medicines for plants. But their indiscriminate use may cause considerable hazards to health and environment. When pesticides are applied on plants for pest control, only a very small part (<0.1%) actually reaches the sites of action, with the larger proportion being lost and ultimately accumulates in the soil and leaches to water resources. Therefore, the understanding of adsorption behaviour of carbofuran becomes an important phenomenon, to describe the fate of carbofuran in soils and ground water. The behaviour of pesticides in the soil depends on factors such as the physico-chemical properties of pesticides, organic content, clay content and the amount of the pesticide applied. This review primarily ascertains the influence of soil organic matter, clay content, pH and temperature on carbofuran behaviour in soils and their effect on adsorption and thermodynamic parameters.

Keywords: Carbofuran; adsorption; organic matter; clay content; Groundwater Ubiquity Score.

Introduction:

Carbofuran (2,3-dihydro-2,2- dimethylbenzofuran-7-yl methyl carbamate) is a systemic, broad-spectrum carbamate insecticide/nematicide which is widely used for the control of nematodes in soils [1].



It is widely used for the control of soil dwelling and foliar feeding insects and nematodes on a variety of agricultural crops including maize, corn, rice, potatoes, alfalfa and grapes[2]. Carbofuran is highly toxic (oral LD_{50} 8–11 mg/kg in rats) and has been classified as highly hazardous pesticide[3]. The toxicity of carbofuran includes inhibitory effects on cholinesterase enzyme and irreversible neuromuscular disturbance on inhalation[2]. Being highly water soluble (solubility 351 mg/L at 25ºC), it finds its way into water sources due to high mobility[4] and may cause toxicity to invertebrates, fish and birds.

In general the fate of pesticide is mostly played out in the soil as the latter is ultimate reservoir for pesticides irrespective of their application target. These chemicals enter the soil in different ways i.e. with washing of remaining deposits on crops by rain or irrigation water and incorporated with crop residues. In soil environment, the pesticides get fractionated between soil solution phase (in free form) and soil solid phase through adsorption on clay and organic fractions (in bounded form)[5]. The adsorption of pesticides affects various processes like bioactivity, mobility, persistence, toxicity, volatilization and bioaccumulation because all these phenomena are operative only on the unadsorbed fractions of pesticide[6]. All these processes influence the extent of surface and ground water contaminations. Therefore, from environmental point of view, thorough understanding of adsorption of carbofuran pesticide on soil is paramount for the prediction of its movement in soils and aquifers.

To accomplish above objectives, it is therefore, inevitable to find the factors which affect the adsorption of carbofuran in soils. The influence of following parameters viz. pH, temperature, organic content and clay content has been studied to check their effect on leaching of carbofuran and on adsorption and thermodynamic parameters.

Adsorption:

Adsorption is a surface process that leads to transfer of a molecule from a fluid bulk to solid surface. There are three different types of adsorption isotherms which are used to determine the percentage of adsorption. These are Freundlich, Langmuir and BET isotherm. But the most commonly studied isotherm for adsorption of carbofuran is Freundlich isotherm.

Parameters studied for adsorption of carbofuran

Freundlich Adsorption Isotherm

The Freundlich adsorption isotherms equation relates amount of pesticide adsorbed to the concentration of the pesticide in solution as[7,8]:

$$X = K_f C_e^{nf}$$

where X is the amount of pesticide adsorbed mg/kg on the adsorbent, C_e is the equilibrium solution concentration (mgL^{-1}) and K_f and n_f are sorption coefficients that characterize the sorption capacity of adsorbent. The sorption coefficients K_f and n_f are calculated from the least square method applied to the linear form of the Freundlich's sorption equation:

$$\log X = \log K_f + n_f \log C_e$$

The adsorption parameters

Another parameters for the adsorption process viz. distribution coefficient or soil-adsorption coefficient (K_d) (in L/Kg of soil), soil organic carbon partition coefficient (Koc) (in L/Kg of organic carbon content of soil) have been calculated by using following equations[7-8].

$$K_d = X/ C_e$$

$$K_{oc} = K_d \times (100/\%OC)$$

Groundwater Ubiquity Score (GUS index)

The GUS index assesses the leachability of molecules and the possibility of finding these compounds in groundwater [9,10]. It is calculated by the equation:

$$GUS = \log(t_{1/2}) \, [4-\log(K_{oc})]$$

Where $t_{1/2}$ is pesticide persistence (half life, in days) and OC is organic carbon content of the soil. GUS index is used to study the leaching behaviour of pesticides and these can be classified as leacher in which GUS values are higher than 2.8, transition with GUS values is between 1.8 and 2.8 and non-leacher pesticides, GUS value is lower than 1.8.

The thermodynamic parameters

Gibb's free energy (ΔG^o), enthalpy change (ΔH^o) and entropy change (ΔS^o) have also been calculated by using following equations [11].

$$\Delta G^o = -RT \ln K_d$$

$$\ln\{(K_d)_2/(K_d)_1\} = \Delta H^o/R \, \{(T_2-T_1)/T_1T_2\}$$

$$\Delta S^o = ((\Delta H^o - \Delta G^o)/ T$$

where R = gas constant and T = absolute temperature.

Adsorption also determines the availability of pesticides in the soil solution, (which governs the amount of pesticides available for uptake by plants). The distribution of pesticide in soil depends on pesticide movement, degradation rate and on distribution coefficient K_d of pesticide between the aqueous phase and soil phase i.e. pesticide adsorption.

This distributions is generally influenced by three factors:

1. Pesticide properties, including its physical characteristics and susceptibility to chemical and microbial degradation;
2. Soil properties, including its organic and clay contents, pH, depth, moisture, texture, and structure;
3. Weather conditions, including the amount, frequency, and intensity of rainfall and temperature.

Therefore the impact of various factors on fate of carbofuran in soils has been studied by various authors as follows:

Factors influencing the fate of carbofuran in soils

Effect of organic content and clay content

Soil organic matter is one of major adsorbent for pesticides in soil and largely affects the adsorption capacity of pesticides. It is found that the amount of pesticides adsorbed by soils increases as the total soil organic carbon content and clay content increase. This is because the particles of organic matter or clay provide soils with an increased number of adsorptive sites onto which pesticides molecules can bind[12,13] , thus increases retention time of pesticide in the soil and reduces the leaching and surface run-off. Similar trend of adsorption dependence on organic content and clay content were found by adsorption of carbofuran on acidic soils[14]. The fact that more carbofuran was adsorbed in clay than in sandy clay soil, may be due to the high soil organic matter content in the clay soil [15] . Similar results were reported by other workers, where, compost soil showed the maximum adsorption capacity, The order of adsorption capacity of various soils were: compost soil > clayey soil > red soil > sandy soil, which is due to significant role of clay content and organic matter [16].

A positive trend between adsorption and organic matter content was observed in adsorption study of carbofuran on loamy and sandy soils [17]. Carbofuran adsorption was higher in loam soil than in sandy loam soil due to the presence of greater amounts of organic matter and clay content in loamy soil. However, in some studies, carbofuran adsorption could be correlated better with the clay content of the soils rather than with their organic matter content[18,19]. Similar results have been reported by a number of other workers when soil organic carbon contents is low [20].

Effect of pH

The adsorption of pesticides is highly dependent on pH, since it has strong influence on the surface charge and varies with the nature of pesticide and soil composition. The variations of the pH can affect the state of the ionic species in solution. Adsorption of carbofuran increase as pH increased from 2 to 8. From pH 8 to 10, there was a slight reduction in adsorption capacity. This may be due to the masking of functional groups at elevated pH[16]. Similar results of increased adsorption were reported as pH was raised to 6.5-7.5 (neutral) and 7.5-8.5 (alkaline) [20]. However adsorption of carbofuran on carbon slurry shows a small decrease for an increase in pH from 2.0 to 8.0. On further increase in pH up to 12.0 the percentage adsorption becomes poor [21]. Similar results of adsorption of carbofuran on activated carbon were reported by other author also[22].

Effect of temperature on adsorption

Temperature is another important factor affecting adsorption of pesticides. With increase in temperature adsorption capacity of carbofuran decreases[15]. Generally, when the temperature increases, the pesticide becomes more soluble. As a consequence, it is less retained by the adsorbent. The lower adsorption of carbofuran with increase in temperature is partly due to weakening of attractive forces between carbofuran and soil sites and partly due to enhancement of thermal energies of adsorbate [12,13].

The adsorption parameters

The distribution coefficient (K_d) and soil organic carbon partition coefficient (Koc)

The value of K_d represents the extent of adsorption and in general higher the K_d value, the greater is the pesticide adsorption. Though, K_d for a pesticide is soil-specific and its value varies with soil texture and organic matter content, the soil organic carbon partition coefficient (Koc) is less soil specific and has been calculated by normalizing adsorption coefficient (K_d) with the organic carbon (OC) content of the soil and gives more accurate results with regards to mobility of a pesticide in any kind of soil. K_d values increases with the increase in soil organic content[12,13]. Low K_d values for adsorption of carbofuran on lateritic soil implies low affinity of carbofuran for lateritic soil[20]. The pesticide which has lower K_d and Koc values is considered to be more mobile. Therefore, the constants which appeared in the adsorption models can be used to predict the transport of pesticide in the soil[20]. Similar results of dependency of K_d with organic carbon content was found by other authors also [18].

The mobility of carbofuran can be predicted more precisely by Koc values, which indicate that carbofuran is moderately[24, 25] to highly mobile[15, 26] in soils.

The groundwater ubiquity score (GUS index)

GUS index is the most commonly used model which determines the leaching potential of Carbofuran. The GUS for carbofuran was from 2.22 to 2.38, classifying it as a transient pesticide[12] and 2.71-3.22 which presented a high leaching potential [13] therefore it possesses a real hazard to groundwater contamination at greater extent. The GUS was found more than 2.8 by other authors also, confirming the high mobility of carbofuran[26, 27].

Thermodynamic parameters:

The spontaneity of adsorption can be guided by calculations of thermodynamic parameters such as change in (ΔG^o), change in enthalpy (ΔH^o) and change in entropy (ΔS^o). The negative value of (ΔG^o) showed that the interaction of carbofuran with the soil was thermodynamically spontaneous process. The negative values of (ΔH^o) indicates that the interaction of carbofuran with the soil is an energetically favourable exothermic process. The negative value of ΔS^o indicates decrease in randomness with adsorption.[12, 13, 16, 18, 19, 28]

Conclusion:

Soil properties play a major role on the adsorption behaviour of carbofuran in soils. The factors such as organic matter, clay content, pH and soil temperature affect the soil properties and influence adsorption and thermodynamic parameters.

The observed GUS value of carbofuran, classifies it as a transition leacher in terms of leaching behaviour, thereby it poses potential risk to aquatic environment. Hence, this insecticide should be used judiciously to prevent surface and groundwater contamination. The mobility of the insecticide into ground water can be reduced by adding organic amendments such as farmyard manure and compost with higher organic content which will increase its adsorption and reduce the mobility of the insecticide.

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NANO FERTILIZERS

A. Tharun Kumar*[1], M. Yasodha[2], Sushma Sannidi[1], Madhurya D[1] and Vidhyashree B. S.[3]

[1]Department of Agronomy, College of Agriculture, Rajendranagar,
Prof. Jayashankar Telangana State Agricultural University, Hyderbad, Telangana 500030

[2]Department of Agronomy, Amrita School of Agricultural Sciences,
Amrita Vishwa Vidyapeetham University, Coimbatore - 642 109

[3]Department of Agronomy, University of Agricultural sciences,
Dharwad, Karnataka, India -580005

*Corresponding author E-mail: tharunagronomy2017@gmail.com

Abstract:

The agricultural sector has a number of challenges, one of which is ensuring enough nutrient bioavailability to plants. As a result, the presence of methods for controlled release of nutrients, as well as unique ways that do not create detrimental effects, is critical for planting. Nanotechnology in agriculture has a number of advantages, including better nutrient utilisation by plants and less waste. Nanofertilizers are an emerging technology and a growing class of agrochemicals that could help farmers establish more sustainable farming practises. Based on this, the current work attempts to update and explore some important points about these nano materials, such as different production processes, potential mechanisms for nano fertiliser capture by plants, and the benefits and drawbacks of employing these materials. Nano fertiliser is a useful technique in agriculture for improving crop growth, yield, and quality metrics by increasing nutrient use efficiency, lowering fertiliser waste, and lowering cultivation costs. The current chapter summarises the mode of action of nano fertilisers in the plant system, as well as their impact on crop development, yield, quality, NUE, and abiotic stress and heavy metal toxicity reduction.

Keywords: sustainable agriculture, agrochemicals, nano fertilizers

Introduction:

According to the UN DESA research, the present global population of 7.7 billion people will grow to 8.5 billion by 2030, 9.7 billion in 2050, and 11.2 billion in 2100. As a result, the current situation necessitates higher food production. To feed all of these people adequately, total food consumption will need to increase by 50-70 percent (Fehr *et al.*, 2015)

Intensive agriculture is one of the most effective tools for increasing food production by multiples in order to feed an ever-increasing population. Intensive agriculture is benefiting from high-dose nutrient-responsive crops, which has resulted in farmers applying more fertilisers.

Fertilizers are now being discovered to play a significant role in enhancing food production, particularly in underdeveloped countries. (Naderi *et al.*, 2013). According to studies conducted in India, the current NPK fertiliser utilisation ratio is 10:2.7:1, which is lower than the optimal NPK fertiliser ratio of 4:2:1, which is ideal for crop productivity.

Synthetic fertilisers have a significant impact on global food security, and without them, we would only be able to produce half as much food as we do now. (Stewart and Roberts, 2012). Fertilizer is responsible for about 35-40% of crop production." (Nagula and Ramanjaneyulu, 2020). Nonetheless, fertiliser usage efficiency has decreased over time, contaminating fertile soils, water bodies, and the Agri environment as a result of leaching, volatilization, denitrification, and fixation, among other things. (Baligar and Bennett, 1986). The fertiliser response ratio has dropped dramatically from 13.4 kg grain per kilogramme of nitrogen applied in the 1970s to 3.7 kg grain in 2005.(Biswas and Sharma, 2008). The percentage of crop loss is increasing every year nearing 25 to 30% due to the great extent of multi-nutrient deficiencies which directly affect crop production. “The extent of nutrient deficiencies in the country are in the order of 89, 80, 50, 41, 49 and 33% for N, P, K, S, Zn and B, respectively”.(Subramanian and Tarafdar, 2011)

Crop loss is increasing every year, approaching 25 to 30 percent, due to widespread multi-nutrient deficits that have a direct impact on crop yield. "Nutrient inadequacies in the country range from 89 to 80 percent, 50 to 50 percent, 41 to 49 percent, and 33 percent for N, P, K, S, Zn, and B, respectively." (Rakshit *et al.*, 2012). When it comes to micronutrients, the majority of them have an efficiency of less than 5%. As a result, there is an urgent need to adapt sustainable alternative crop production systems.

Scientists from all over the world have developed technologies such as variable fertiliser application rates, large size granules, neem coatings, water-soluble fertilisers, and so on, but nutrient utilisation efficiency still has to be greatly improved. For nearly 15 years, there has been a growing interest in the application of nanotechnology in agriculture. Rodrigues *et al.* (2017) found a number of possible nanotechnology applications for improving sustainable agri-food systems Recent nanotechnologies for plant nutrition and pest management, such as controlled release technique and targeted delivery of agrochemicals (fertilisers and insecticides), are promising technologies for increasing food safety and security by eliminating residual effects in the agricultural ecosystem (Subramanian and Tarafdar, 2011).

Nanotechnology is revolutionizing several industries in the modern world, including information technology, computers, the energy industry, medical, pharmacy, cosmetics, and the food industry. Nanotechnology in agriculture is still in its infancy, and farmers will need to wait a long time for it to mature and reach its full potential.

Nanotechnology's invasion into agriculture began in 1970 with the use of nanoparticles to transmit genes. Precision agriculture, food packaging, plant breeding, and nano-based products such as nano fertilisers, nano pesticides, nano herbicides, nano sensors, nano membranes, and nano magnets are all affected by nanotechnology. A nano fertiliser is a structure or adsorbent with a nano size of 1-100 nm that distributes macro and micronutrients to the crop. Small size, large surface area, fertiliser stability, time-controlled, gradual, and precise release are all significant qualities of nano fertilisers.

Definition:

Nanotechnology is a science dealing with the manipulation of materials at atom level, molecular and macromolecular scales, in the range of 1-100 nm, which results from unique physical and chemical properties unlike original form makes novel applications possible. Nano fertilizers are the nano materials fortified or encapsulated with one or more nutrients, that can slowly deliver nutrients to crops. Norio Taniguchi coined the term nano technology, "Nano" is a Greek word that means "dwarf." and Mr. Richard Feyman, a physicist from the United States, is the father of nanotechnology.

Different kinds of encapsulation methods include (a) encapsulation of nutrients with nanomaterials like nanotubes or nano porous materials, (b) coating of nutrients with a thin protective layer of polymer and (c) formulations which can deliver nutrients as particles or emulsions of nanoscale dimensions (Derosa *et al.*, 2010).

Nano fertilisers have special features that allow them to give nutrients to crops as needed. The designer molecules operate as a nutrition storehouse, releasing nutrients through a plant-root-activated mechanism. When compared to ordinary fertiliser, the efficiency of this nutrient can be increased by several times.

Classification:

Types of Nanomaterials:

1. Carbon-based nanomaterials: These nanomaterials are mostly made of carbon and come as hollow spheres, ellipsoids, or tubes. Fullerenes are spherical carbon-based nanoparticles, while nanotubes are cylindrical carbon-based nanostructures.

2. Metal-based nanomaterials: Quantum dots, Nanogold, Nanosilver, and metal oxides such as titanium dioxide, zinc oxide, magnesium oxide, iron oxide, and others are among these nanomaterials.

3. Dendrimers: Dendrimers are branching polymers with a significant number of chain endings on their surface that are nanoscale in size. These can be changed in a variety of ways in order to accomplish certain chemical actions that are meant to be performed. Having this property dendrimers can be used as a catalyst and its three-dimensional structure with inner cavities allows us to use dendrimers for drug delivery by placing the drug molecules inside (Astruc *et al.*, 2010)

4. Nanocomposites: A nanocomposite is a composition created by mixing nanoparticles with additional nanoparticles or bigger bulk-type elements. These are commonly employed to improve other materials' mechanical, thermal barrier, and flame-retardant qualities (Ajayan *et al.*, 2003)

Types of nano fertilizers:

Different Nano fertilisers, such as Nano-zeolite based fertilisers, Nano hydroxyapatite based fertilisers, Micronutrient based nanoparticle-based (Zn, Fe, Cu, Mo, TiO_2, etc.) fertilisers, Nano biofertilizers, and others, were available based on their adsorbent material.

Preparation/ Synthesis of nano fertilizers

Nanomaterials or nanoparticles for nano fertilisers can be made in variety of ways, including top-down, bottom-up, and biological methods.

1. The top-down approach:

It is the most widely used physical approach for making nano fertilisers. It is made by reducing the size of bulk materials into nanoscale well-organized assemblies using grinding, sputtering, and thermal evaporation. Top-down synthesis is a material-milling-based fast synthesis process. The low control of nanoparticle size and a higher quantity of contaminants are two drawbacks of this method. (Subramanian and Tarafdar, 2011).

2. The bottom-up approach:

It starts at the most fundamental level, with chemical processes to build up nanoparticles at the atomic or molecular level. Because it is a chemically controlled process, this method offers the advantage of better controlling particle size and eliminating contaminants. (Zulfiqar *et al.*, 2019). The following techniques were used in the bottom-up chemical approach.

- Sol-gel Techniques
- Co-precipitation
- Microwave synthesis
- Microencapsulation
- Hydrothermal methods
- Polyvinyl pyrrolidone (PVP) method

3. Biological method – Bottom-up approach:

The Biological method – bottom-up approach has precise control on size and toxicity is less, but synthesis is very slow. Nanomaterial is prepared using living cells of plants, algae and fungi.

Ex. *Aspergillus terreus* CZR-1 produce the nanoparticles of Zn, Mg, P, Fe

Bacillus megaterium JCT-13 produce the P nanoparticle

Penicillium solitum TFR-24 produce the K nanoparticles etc.

4. Nutrient loading:

In living systems, nanoparticles are more efficient at delivering nutrients to specific target areas. Nutrient loading on nanoparticles is typically accomplished through (a) nutrient attachment to nanoparticles, (b) nutrient adsorption mediated by ligands on nanoparticles, (c) nutrient encapsulation with a nanoparticulate polymeric shell, (d) entrapment of polymeric nanoparticles, and (e) nutrient nanoparticle synthesis. (Dey *et al.*, 2018). Here are some of the flow charts to prepare nano fertilizers.

5. Preparation of zeolite-based nitrogen fertilizers by liquid immersion hydrothermal technique

Step 1. Zeolite adsorbent is preheated (150° C for 3 days) in a hot air oven for efficient N adsorption

Step 2. Urea solution is heated at 115°C till it changes from crystal structure to liquid

Step 3. The prepared mixture is heated continuously till the liquid fertilizer is completely adsorbed on the zeolite.

Step 4. Constant cooling (50°C) of solid material and adding polymer (Carboxyl methylcellulose sodium salt) with continuous mixing (Manik and Subramanian, 2014).

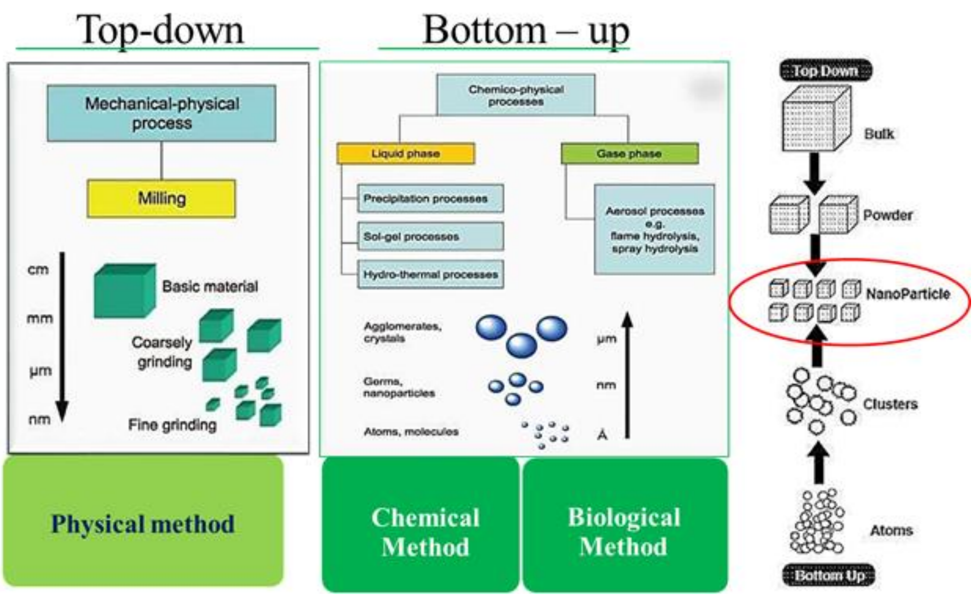


Figure 1: General approach for Nano fertilizer preparation procedure

6. Preparation of ZnO nanoparticles (25 nm) using oxalate decomposition technique

Step 1. Equimolar concentration (0.2M) of zinc acetate and oxalic acid are mixed.

Step 2. Precipitated zinc oxalate is collected rinsed with double deionized water and dried in air.

Step 3. Zinc oxalate is ground well and decomposed in the air by placing it in a preheated furnace for 45 min at 500^{o}C.

Step 4. The samples should be characterized using TEM, SEM and X –rays diffraction techniques.

Step 5. ZnO 25 nm nanoparticles are thus synthesized (Prasad *et al.*, 2012).

7. Preparation of nano–Si

Step 1. Adsorbent Zeolite is preheated (150^{o}C for 3 days) in a hot air oven for efficient adsorption of nitrogen

Step 2. Urea solution is heated at 115^{o}C till it changes from crystal structure to liquid

Step 3. The prepared mixer is heated continuously till the liquid fertilizer is completely absorbed on the zeolite.

Step 4. After Constant cooling (50^{o}C) of solid material polymer (Carboxymethyl cellulose sodium salt) should be added with continuous mixing (Wang *et al.*, 2015).

8. Preparation of Nano biofertilizer:

An Indian agro-scientist, Dr J. C Tarafdar *et al.* (2014)has innovated nano fertilizers using biosynthesis, for the first time in the world.

Step 1. Fungi, *Rhizobium bataticola* TFR-6 is grown in a 250-mL Erlenmeyer flask containing a 100-mL PD broth medium by adjusting the pH of the medium to 5.8.

Step 2. The culture was subjected to continuous shaking on a rotary shaker (150 rpm) at 28^{o}C for 72 h.

Step 3. After complete incubation, fungal balls of mycelia were separated from the culture broth by filtration process using Whatman filter paper number 1 under a biosafety cabinet

Step 4. Fungal mycelia were washed thrice with sterile double-distilled water.

Step 5. The harvested fungal mycelia (20-g wet weight) were re-suspended in 100-mL sterile Milli-Q-water in 250-mL Erlenmeyer flask and again put into a rotary shaker (150 rpm) at 28oC for 12 h.

Step 6. The cell-free filtrate was obtained by separating the fungal biomass using a 0.45l membrane filter

Step 7. Using cell-free filtrate, a salt solution of aqueous zinc oxide was prepared with a final concentration of 0.1 mM in Erlenmeyer flasks.

Step 8. The entire mixture was kept on a rotary shaker at 28^{o}C at 150 rpm. The reaction was allowed to carry out for a period of 4 h**.**

Step 9. The biotransformed product was collected periodically (1 h interval) for characterization of particle size using a particle size analyzer

9. Nanoparticle analysis:

Dynamic Light Scattering (DLS) Analysis: It is to know the size distributions of zinc nanoparticles with histogram. The histogram will show the differential number %age indicating the size distribution and cumulative number %age indicating the mass distribution of nano fertilizer particles.

Transmission Electron Microscope (TEM) and High Resolution (HR)-TEM is used for confirmation of the size and shape of nano fertilizer particles.

Electron Dispersive X-Ray Spectroscopy (EDS) Analysis is used for the determination of the elemental composition and purity percentage of the sample by an atom of a particular metal in nano fertilizer (Raliya and Tarafdar, 2013).

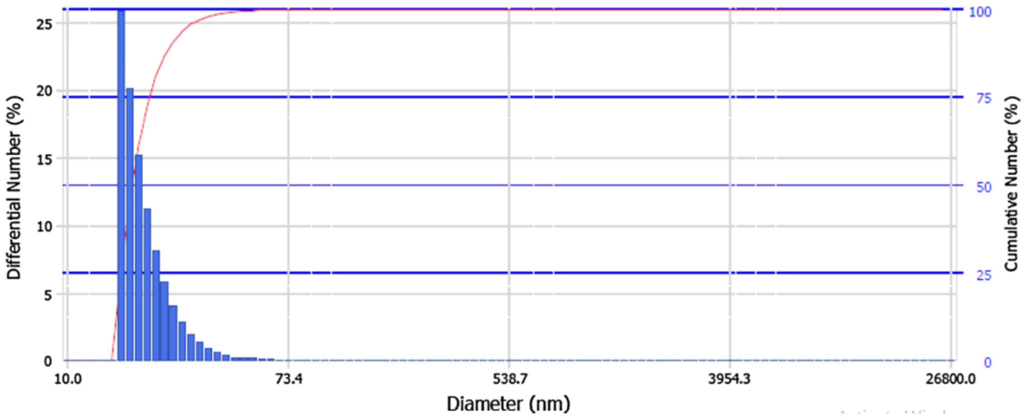


Figure 2: Dynamic Light Scattering (DLS) analysis

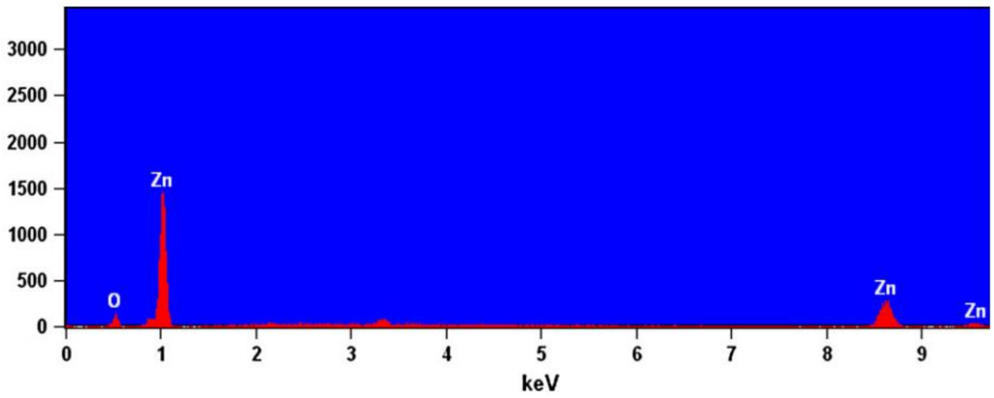


Figure 3: Transmission Electron Microscope (TEM) and High Resolution (HR) TEM

As a result, it is apparent that there are numerous methods for producing nanofertilizers, necessitating the selection of the most appropriate method for each situation and final application. The decision must be based on the production, use, preparation, and final application's economic viability. Another significant issue to consider is the performance of the end products, which necessitates knowledge of the mechanisms of nutrient absorption in the culture under investigation.

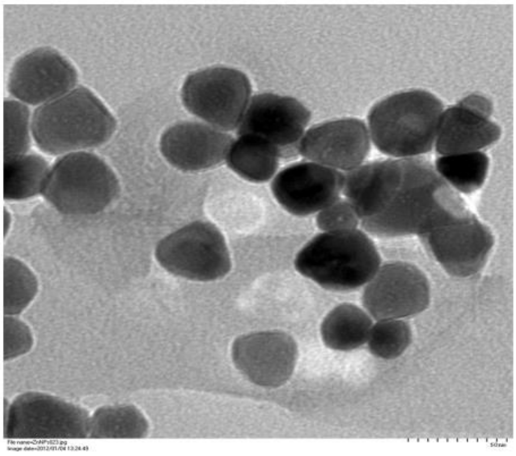


Figure 4: Electron Dispersive X-Ray Spectroscopy (EDS) analysis

Methods of Nano fertilizer application and nutrient uptake mechanism:

Nano fertiliser can be used as a foliar spray or in the soil. However, more research is needed to see if this technique is more efficient for nutrient utilisation for various crops in varied soil and environmental conditions. Root junctions, wounds, root, shoot, and leaf tissues are potential entry points for nanoparticles into the plant system (e.g., cuticles, trichomes, stomata, stigma, and hydathodes)(Wang *et al.*, 2016)**.**

The pore diameter of the cell wall is critical for controlling nanoparticle penetration through the cell wall (5-20 nm)(Fleischer *et al.*, 1999). Nanoparticles or nanoparticle aggregates with a diameter smaller than the pore size of the plant cell wall might so easily penetrate through the cell wall and reach the plasma membrane. (Navarro *et al.*, 2008).

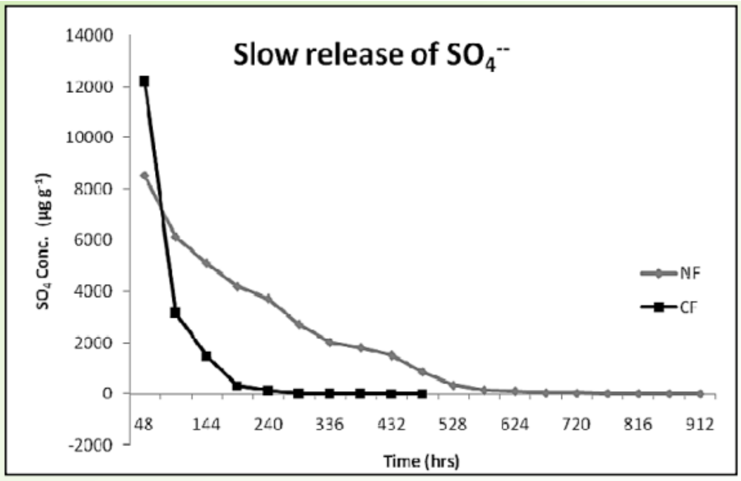
As a result, one of the major barriers to nanoparticle entry into the plant system is assumed to be pore size. The largest size of nanoparticles that can penetrate and collect inside plant cells, according to various studies, is between 40 and 50 nm, and this size range is referred to as the exclusion limit. (Sabo-Attwood *et al.*, 2012)..

Nano-fertilizers applications:

Effect of nano fertilizer application on growth and yield parameters of crops

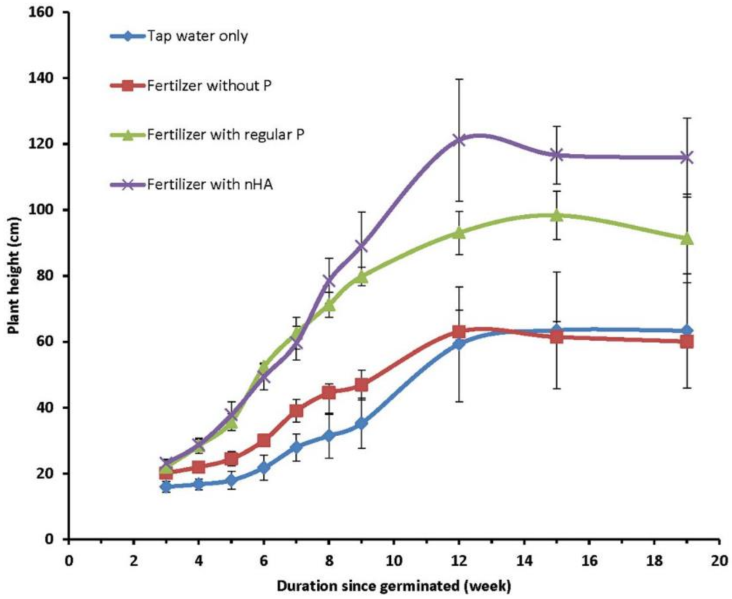
Nano-fertilizers improve crop output mostly due to enhanced nutrient availability. Eventually, increased physiological and biochemical activity in plant systems, such as photosynthesis and translocation, leads to increased photosynthetic accumulation and translocation. In research tests, foliar spraying of nano NPK formulations and micronutrients mixture boosted the plant height and number of branches in black gram plants (Marimuthu and Surendran, 2015), leaf dry weight of peppermint (Rostami *et al.*, 2017) and growth of leaves in wheat (Abdel-Aziz *et al.*, 2018) due to enhanced availability of nutrients and easy penetration nutrient source.

Foliar spray of NPK nanofertilizers in chickpea increased the yield and yield components as a result of increased growth hormone activity and enhancement of metabolic process, tended to increase in flowering and grain formation (Drostkar *et al.*, 2016). Significant increases of total and open bolls per plant, boll weight and seed cotton yield with the foliar nanofertilizers application than soil application (Sohair *et al.*, 2018). According to Drostkar *et al.* (2016), foliar application of zinc, iron, and NPK manipulates chickpea growth, resulting in improved yield and yield components.



A comparative study of the release of sulphate (SO_4^{2-}) from fertilizer loaded SMNZ and $(NH_4)_2$ SO_4 fertilizers were performed using the percolation reactor. The results showed that the SO_4^{2-} supply from fertilizer loaded SMNZ was available even after 912 h of continuous percolation, whereas SO_4^{2-} from $(NH_4)_2$ SO_4 was exhausted within 384 h. These properties suggest that SMNZ has a great potential as the fertilizer carrier for slow release of SO_4^{2} (Thirunavukkarasu and Subramanian, 2014)

Zinc nano fertilizer had significantly increased shoot length, root length, root volume, plant dry biomass and grain yield of pearl millet (*Pennisetum americanum* L.)(Tarafdar *et al.*, 2014), plant fresh weight and dry weight, number of bolls per plant and boll weight of cotton crop (Rezaei *et al.*, 2014) and plant height, leaf number and fresh and dry weight of savory plant (Vafa *et al.*, 2015). This was due to increased availability of zinc, which is a precursor element of natural auxin – indole aceti acid (IAA). As a result improved physiological processes like chlorophyll content and antioxidant activity had been noted. Nano-chelate zinc enhanced the shoot and root growth due to improved peroxidase, catalase and polyphenol oxidase enzymes activity in cotton and soybean crops (Rezaei *et al.*, 2014; Weisany *et al.*, 2012). Groundnut crop pod yield gets increased with the application of nano-scale zinc oxide compared to ZnSO4 application, on account of nano-scale zinc is absorbed by plants to larger extent than its chemical form (Prasad *et al.*, 2012).



Some soluble phosphate salts, heavily used in agriculture as highly effective phosphorus (P)fertilizers, cause surface water eutrophication, while solid phosphates are less effective in supplying the nutrient P. In contrast, synthetic apatite nanoparticles could hypothetically supply sufficient P nutrients to crops but with less mobility in the environment and with less bioavailable P to algae in comparison to the soluble counterparts. Thus, a greenhouse experiment was conducted to assess the fertilizing effect of synthetic apatite nanoparticles on soybean (Glycine max). The particles, prepared using one-step wet chemical method, were spherical in shape with diameters of 15.8 6 7.4 nm and the chemical composition was pure hydroxyapatite. The data show that application of the nanoparticles increased the growth rate and seed yield by 32.6% and 20.4%, respectively, compared to those of soybeans treated with a regular P fertilizer ($Ca(H_2PO_4)_2$). Biomass productions were enhanced by 18.2% (above-ground) and 41.2% (below-ground). Using apatite nanoparticles as a new class of P fertilizer can potentially enhance agronomical yield and reduce risks of water eutrophication (Liu and Lal, 2014)

It was suggested that nanofertilizer application increased grain zinc content without affecting grain yield, protein content, spikelets per spike, 1000 kernel weight, etc., owing to enhanced enzyme activity and carbohydrate metabolism leading to an an increased yield (Afshar and Rahimihaghighi, 2014) . Nano-Fe fertilizer application at tillering and stem elongation did increase the number of seeds per spike, whereas early application of Fe fertilizer decreased the number of seeds per spike in wheat. Hence, the foliar application of Fe was more suitable than seed dressing or soil application attributable to being a suitable time for seed formation. In addition, Fe availability can increase the leaf area index, leaf area duration and decreased leaves

242 Foliar application of nanofertilizers in senescence that can increase economic yield (Armin *et al.*, 2014).

Effect of nano fertilizers on quality parameters

Nano-fertilizers can improve nutrient availability. This helps to increase quality parameters like protein, oil and sugar content in plants by increasing the rate of the chemical reaction or synthesis process in plant cells. Nano formulation of zinc and iron increased the total carbohydrate, starch, indole-3-acetic acid, chlorophyll and protein contents in crops (Wa Al-Juthery and Hilal Obaid Al-Maamouri, 2020). Singh (2015)reported that seed oil content increased with increased concentration of nano ZnS in sunflower. Fibre quality parameters of cotton like uniformity ratio and fibre strength were improved by the application of metal oxide nanoparticles than control (Mahil and Kumar, 2019). Prasad *et al.* (2012) found that the application of fertilizer in nano form is completely controlled and has led to an increase yield and protein content in peanut. Sham (2017) reported that foliar application of ZnO nanoparticles increased the quality parameters like oil content in sunflower. In peanut, total carbohydrate, total soluble sugars, protein and oil percentages in seeds increased by nanofertilizers (El-Metwally *et al.*, 2018)

Effects of nano-fertilizers on seeds germination and growth parameters of the plant

Numerous scientists have stated that nano-fertilizers affected the growth of seeds and the production of plants. Nanofertilizers can form a favorable foundation for seed growth and production of the plant. Nano formulation of zinc oxide demonstrated higher germination rate and root vigor as compared to bulk zinc sulphate (Kashyap *et al.*, 2015). Positively impacted on soya bean seeds germination (Gruener *et al.*, 2003). Nano-fertilizers cause the fruits to be more succulent and nutritious than natural. It was recorded that the spectra treated seeds grown more up weight, higher rate of photosynthesis, and formation of chlorophyll.

Challenges of nano fertilizer in agriculture:

Nanoparticles can easily enter into the biological system and affect the complete ecosystem due to its nano dimension and unique properties.

Post application constraints

1. Toxicity to Human and Animals

- Nanoparticles could be inhaled, swallowed, absorbed through the skin.
- Trigger inflammation and weaken the immune system.
- Interfere with regulatory mechanisms of enzymes and proteins.
- Lipid peroxidation and DNA damage
- Increased risk of carcinogenesis. (Oberdörster *et al.*, 2005)

2. Toxicity to plants: High concentration of nano-silica silver produced some chemical injuries on the tested plants (cucumber leaves and pansy flowers).
3. Environmental issues: Could accumulate in soil, water and plants.

Application constraints:

Drift losses may occur during application due to their small size

Production Constraints:

The common challenges related to commercializing nanotechnology, are:

- High processing costs problems in the scalability of research & discovery for prototype and industrial production
- Lack of cost-benefit analysis
- Acceptance by farmers

Conclusion:

Nanonutrients are more efficient and cost-effective than traditional nutrients. The use of various types of nano-fertilizers has a significant impact on crop output, natural resource protection, and fertiliser cost reduction in agricultural production. The usage of nano-fertilizers in farm fields will improve the quality of nutrient use. By using the right dosage and concentration, nano-fertilizers encourage good crop development and yield. Crops would be inhibited if a specific cap was exceeded. It would be critical to determine the best fertiliser doses. The production system will be very productive and environmentally friendly in the near future as dosing for different nano subs and crops is optimised. In addition, as compared to the demand for and cost of chemical fertilisers, nano fertilisers are less expensive and are required in less quantities.

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BIO-FORTIFICATION OF CROPS: THE NUTRITIONAL REVOLUTION

Nitika Kalia*, Narender Pal[1], Garima Sethi[2] and Pooja Verma[3]

*Division of PGR-NBPGR; [1]Division of Seed Science and Technology;

[2]Division of Agricultural Chemicals; [3]Division of PGR-NBPGR

ICAR- Indian Agricultural Research Institute, New Delhi

*Corresponding author E-mail: nitikakalia7@gmail.com

Abstract:

Bio-fortification is a sustainable, long-term approach for providing micronutrients to rural communities in underdeveloped nations. More than half of the world's population suffers from vitamin A, iron, and zinc deficiencies. Through supplementation and food fortification, progress has been made in the control of micronutrient deficiencies, but new strategies are required, especially to reach the rural poor. One choice is bio-fortification, which involves improving the nutritional value of staple crops through plant breeding. In order to create crops with higher amounts of micronutrients, a range of procedures are used, including agronomic practices, conventional breeding methods, and transgenic breeding methods. HarvestPlus has recently worked with international partners to introduce bio-fortified crops in underdeveloped nations, including rice, wheat and maize. This has helped the target population overcome micronutrient deficiencies.

Keywords: Bio-fortification, Hidden Hunger, HarvestPlus, nutritional deficiency

Introduction:

Access to a healthy diet is a fundamental right of all human beings. People in developing countries tend to suffer from shortages of minerals and vitamins. The number of undernourished people in the world continued to rise in 2020. In 2020, between 720 and 811 million people faced hunger (FAO, 2021). Many countries have implemented various interventions to address micronutrient malnutrition because it is a critical public health issue. There has been some success in reducing malnutrition through programs such as dietary diversification, food fortification, bio-fortification and supplementation. Among the methods used to improve micronutrient content in crops, Crop bio-fortification is an effective and economical method to enhance micronutrient content in crops, especially staple food crops in developing countries. It refers to nutritionally enhanced food crops with increased bioavailability to the human population that are developed and grown using modern biotechnology techniques, conventional plant breeding, and agronomic practices.

To meet micronutrient and energy needs, a diet that includes fruits, vegetables, and animal products is necessary. However, the majority of people on the planet cannot afford these things.

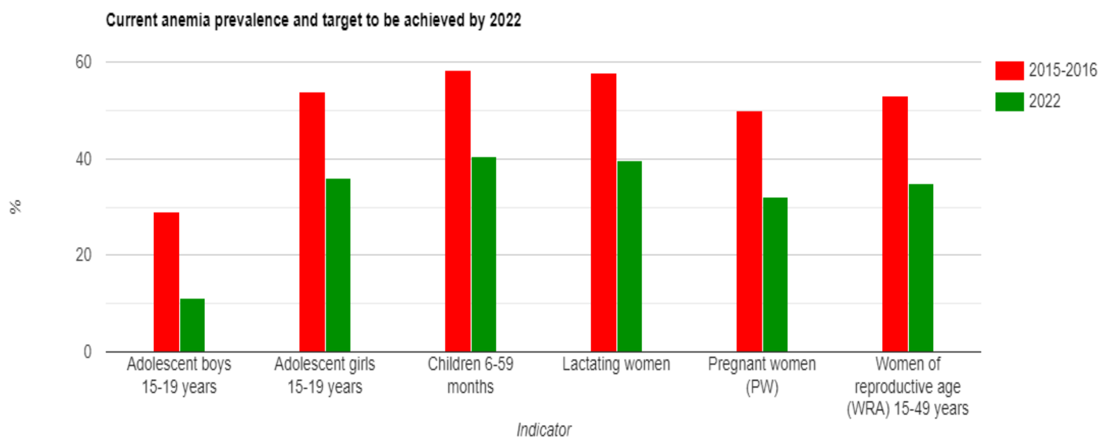
Although practically all plants are capable of producing and storing micronutrients, the edible sections of some plants used to grow staple crops are deficient in some micronutrients including iron (Fe), zinc (Zn), vitamin A, folic acid, etc. Finding a crop with enough nutrients to serve as a perfect and complete diet is difficult. Bio-fortification of staple crops with micronutrients has therefore been proposed as a potential strategy to combat the problem of malnutrition through the enrichment of target food crops to fill the gap in micronutrient ingestion by humans and animals (Nestel *et al.,* 2006). Consuming a lot of food with little variety, primarily one or two staples in developing nations, is the main cause of Fe and Zn deficiencies. Due to extreme poverty, individuals in emerging nations primarily rely on cereal and animal-based foods. Wheat, maize, and rice are these nations' three main basic crops. Through breeding and fertilization, bio-fortification increases the amounts and bioavailability of micronutrients in edible sections of staple crops, hence reducing micronutrient deficiency. The scientific community generally agrees that bio-fortification is a superior technique to supplements and/or food fortification since it is more affordable and sustainable.

Along with the enrichment of staple crops with micronutrients this approach has other advantages like the germplasm can be transferred internationally after the initial outlay to create seeds that can fortify themselves as the current requirement are minimal. Plant breeding is more affordable because of this multiplication impact over time and space. The bio-fortified crop system is very sustainable once it is established. Even if government interest and international financing for micronutrient issues wane, nutritionally enhanced varieties will continue to be planted and consumed year after year.

Problem of 'Hidden Hunger'

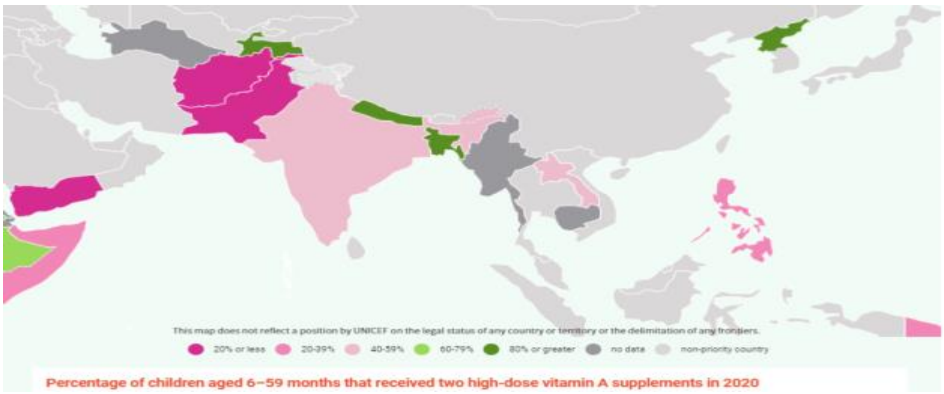
Hidden hunger, also known as micronutrient deficiency. Micronutrients are needed in smaller amounts, which include several vitamins and minerals. Deficiencies in essential vitamins and minerals continue to pose serious threats to populations and economies around the world. Mental impairment, poor health, low productivity, and even death can result from hidden hunger. It is particularly important for women and young children under five years of age to have a balanced diet rich in micronutrients like zinc, iron, and vitamin A. As per "The State of Food Security and Nutrition in the World 2021" 15.3% of Indian population is undernourished, and 30.9% of Indian children (Under the age of 5) are stunted and 17.3 % are wasted. Additionally, anemia is a serious health concern, 53.0% of Indian women of reproductive age (15-49) are affected with this deficiency.

Anemia and iron deficiency reduce individuals' wellbeing, cause fatigue and lethargy, and impair physical capacity and work performance. (Ekta Belwal *et al.,* 2021). In India since 1992, the National Family Health Surveys (NFHS-1-5), have collected extensive demographic, health, and nutrition information so that the Ministry of Health and other agencies can formulate policies and plan programs and help India situate itself in the global community. So far, five surveys have been conducted over a span of almost two decades (1992-2021). (Ekta Belwal *et al.*, 2021).



(Source: https://anemiamuktbharat.info/target/)

Other than anemia, Vitamin A deficiency also threatens people's life. Children living in developing countries are at serious risk of vitamin A deficiency. The vitamin A deficiency may lead to various health issues such as susceptibility to various infections, stunting, eye health, and vision issues. In a broader sense, vitamin A has an important role to play in the regulatory of processes like cellular differentiation and function, such as growth, vision, reproduction, morphogenesis, immunity, etc. According to a report from UNICEF, only two out of five children in need received the life-saving benefits of vitamin A supplementation in 2020. Out of 64 countries deemed 'priorities' for national-level vitamin A supplementation programs, 48 had two-dose coverage estimates available for 2020. Only 11 countries, achieved two-dose coverage of 80 per cent or more in 2020. Two-dose coverage with vitamin A supplements dropped drastically in 2020, due to outbreak of COVID-19 pandemic. In India, about 54% children (aged 6–59 months) received two high-dose vitamin A supplements in 2020. (UNICEF global databases, 2021).



(Source: UNICEF global databases, 2021, based on administrative reports from countries)

The importance of zinc for human health is similar to that of iron and vitamin A. Nutritional zinc deficiency is widespread throughout developing countries. (Mocchegiani *et al.*, 2012). India is a zinc-deficient country. Given deficiency of this essential micronutrient, WHO has reported that about 800,000 deaths happen annually due to zinc deficiency, of which 450,000 are children under the age of five (UNION BUDGET 2020). Zinc is an essential micronutrient for humans and is extensively involved in protein, lipid, nucleic acid metabolism, and gene transcription. (McClung, 2019).

A wide variety of foods contain zinc, including meat, fish, legumes, nuts, and other sources of dietary zinc. However, zinc absorption depends on the substrate in which it is found. A daily intake of zinc is required to maintain a steady state because the body has no specialized zinc storage system. (Rink *et al.*, 2000). Old people aged 60-65 years and older have zinc intakes below 50% of the recommended daily allowance on a given day. UNICEF supplied 50.8 million oral rehydration sachets (ORS) sachets, of which 8.7 million were ORS and zinc co-packs; also 111.9 million zinc tablets, of which 40.9 million were ORS and zinc co-packs.

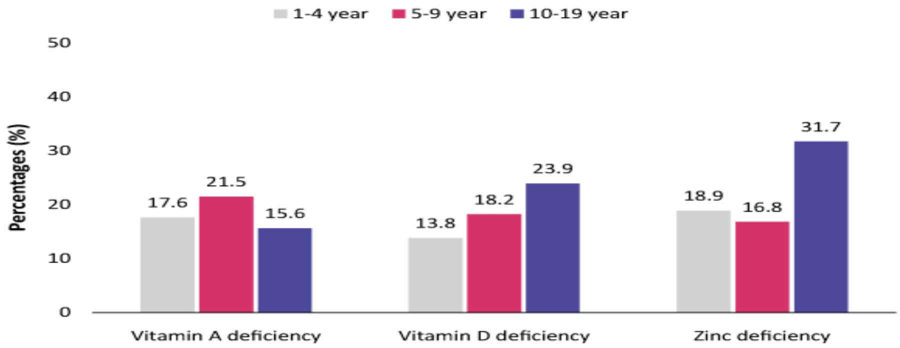


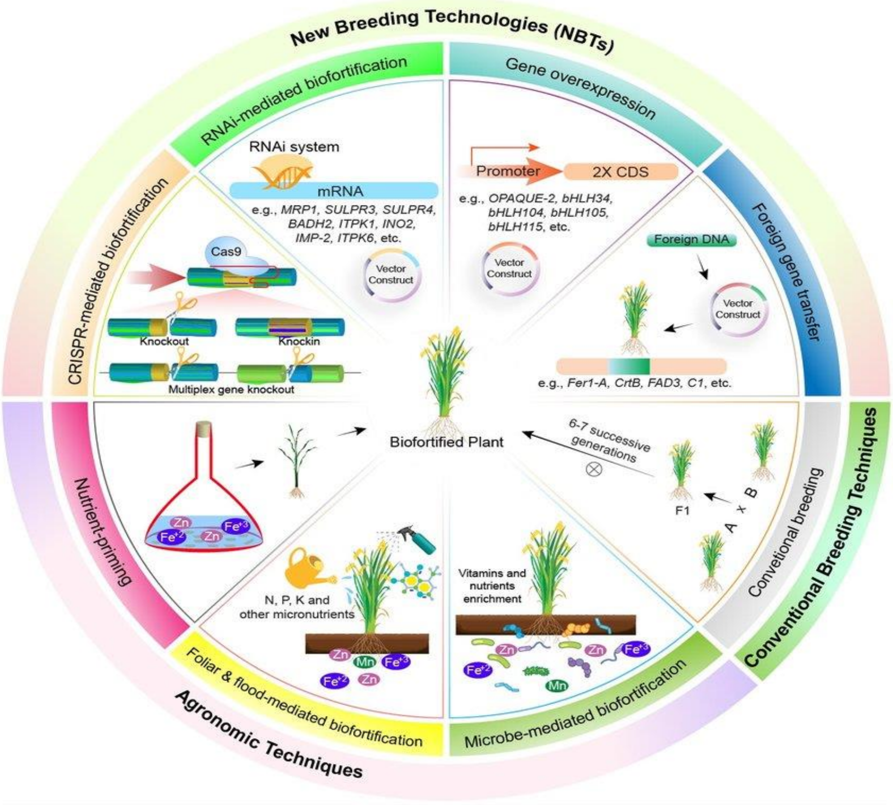
Figure: Percentage of adolescents with Vitamin A, Vitamin D, and Zinc deficiency, India, CNNS (Source: Abhiyaan Monitoring Report)

According to CNNS results (2016-18), zinc deficiency was found in nearly one-third of adolescents aged 10–19 years (32%). Fewer pre-school children aged 1–4 years (19%) and school-age children aged 5–9 years (17%) were found to be zinc deficient. In India, States with a high burden of zinc deficiency among adolescents (10–19-year-olds) were Gujarat (55%), Manipur (53%), Himachal Pradesh and Punjab (both 52%) (WCD Division, NITI Aayog, 2020).

It is possible for nations to overcome malnutrition by addressing all of these deficiencies. One solution pursued by CGIAR researchers is bio-fortification which involves breeding crops to enhance their nutritional content, increase yields, and boost resilience to climate extremes, diseases, and pests. Families in rural areas of developing countries often rely on homegrown staple crops that are cheap, but not very nourishing. This innovative technology aims to change that. With bio-fortification, these families are able to obtain much-needed food security and nutrition.

Methods of bio-fortification

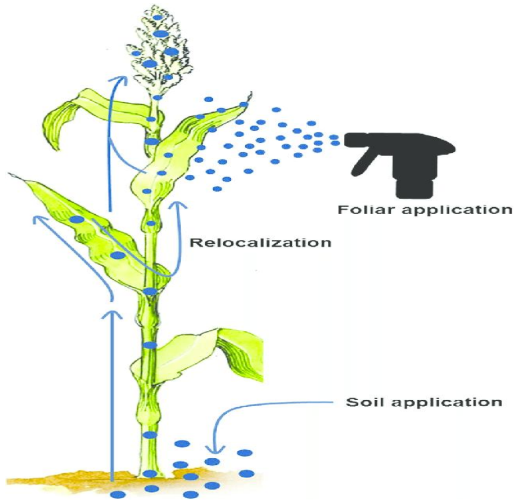
Bio-fortification of essential micronutrients into crop plants can be achieved through three main approaches, namely transgenic, conventional, and agronomic, involving the use of biotechnology, crop breeding, and fertilization strategies, respectively (Garg *et al.*, 2018).



New breeding technologies Source: Shahzad *et al.*, 2021

Agronomic techniques

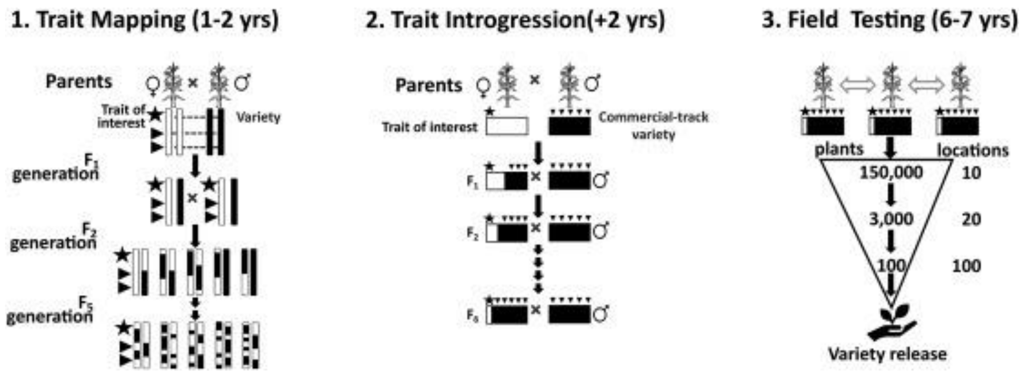
Bio-fortification through agronomic approaches is an economical and easy method but the method of nutrient application, their type, and environmental factors requires great care. (Shahzad *et al.*, 2021). By increasing microbial activity, this approach allows for the efficient utilization of nutrients by plants by increasing their availability, their effective utilization, and their mobility in plants. Microbes like rhizobium, bacillus, azotobacter, actinomycete, and some fungal strains, i.e., *P. indica*, are used to enhance nutrient availability and uptake. Another technique for bio-fortification in crops is foliar application, in which nutrients are applied in liquid form in aerial parts of plants and absorbed through stomata and epidermis. Crops can be bio-fortified with mineral fertilization by flooding. Minerals, i.e., selenium, zinc, calcium, etc., are supplied to crops alongside irrigation. (Shahzad *et al.*, 2021).



Agronomic bio-fortification is the application of micronutrient-containing mineral fertilizer (blue circles) to the soil and/or plant leaves (foliar), to increase micronutrient contents of the edible part of food crops. (Source: A.W. de Valença *et al.*, 2017)

Convention breeding

Convention breeding is the development or improvement of cultivars using conservative tools for manipulating plant genome within the natural genetic boundaries of the species. The process of conventional breeding has evolved over time, creating an effective framework that not only improves crop performance, but also supports development of foods that are safe and nutritious to consume. (Natalie *et al.,* 2020). There are a number of decisions that must be made during plant breeding, including selecting the best parents, cross-pollinating the parents and selecting the greatest progeny. During conventional breeding, from plant population obtained only fraction of population is used further and about majority of plants are discarded. During many stages of the plant breeding process, including trait mapping, trait introgression, and field testing, a few individuals are selected from large populations, which is an important contribution to plant breeding.



General framework of the conventional breeding process that is comprised of three stages (Source: Natalie *et al.*, 2020)

Trait Mapping: The purpose of trait mapping is to identify and confirm the genetic basis of the trait of interest by finding the DNA region linked to the trait (Falconer & Mackay, 1996). In order to map traits, breeding strategies commonly involve breeding parent plants with extreme values of the trait of interest to produce progeny. Identification of the precise location of genes underlying the trait of interest within the identified chromosome is achieved over the subsequent 5–6 generations of progeny plants. (Natalie *et al.,* 2020). After mapping the trait-linked DNA marker that segregates, is then used to develop a DNA marker-based assay, due to which breeders were allowed to conduct rapid molecular screening assays. Due to this one can achieve genetic basis of the trait of interest in thousands of progeny plants, which help in replacing more laborious and resource intensive phenotyping methods.

Trait introgression: The DNA marker-based assay is now ready to be used by breeders for the next stage of breeding of trait introgression to identify and select individual plants with the trait of interest. (Natalie *et al.,* 2020). Plants that carry traits of interest are cross-pollinated with varieties with traits that are commercially suitable and well characterized during trait introgression. Next step is called marker-assisted back-crossing. During which, plant breeders successively breed cycles, repeatedly crosses the same commercial track varieties used in step one with progeny carrying the trait of interest. Parental commercial-track varieties having wide genome marker set is used to select and screen plant with same genetic background. Shifting of genetic background can be done by cross pollinating progeny with the same commercial track parent for 5-6 generations which gives greater proportion of genes from the commercial-track variety.

Field Testing: In this step, the few plants selected from the trait mapping and trait introgression steps are then used as the parental plants for the final step in conventional breeding practices needed to make a commercial variety (Kaiser, *et al.*,2020). The large numbers of progeny plants are evaluated for many agronomic and quality parameters over the course of approximately 6–7 years at an increasing number of geographic or environmentally diverse locations in this "Field Testing" stage of the process (Glenn *et al.,* 2017).

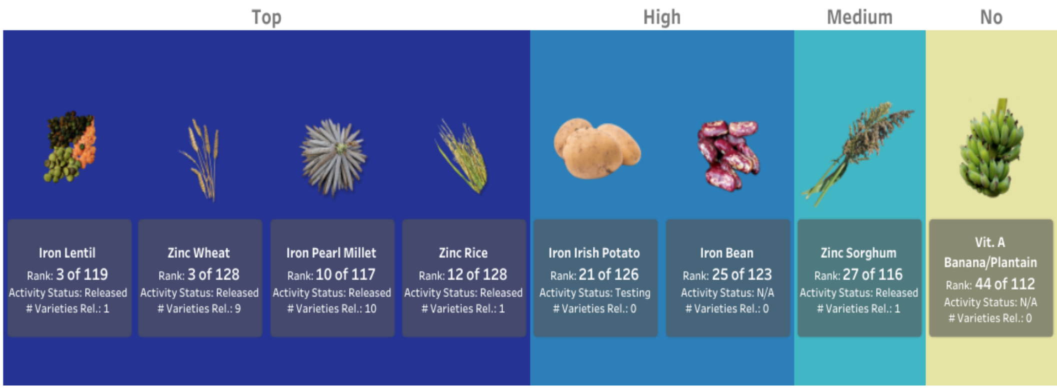
New breeding techniques

The development of new breeding techniques, for instance, transgenic breeding RNA interference (RNAi), and genome editing, are playing key roles in the bio-fortification of crops due to which the potential for the creation of new genetic variations is being explored.

Transgenic Breeding: It is a cost-effective efficient, sustainable approach to combat malnutrition. Limited genetic variety in the gene pool and wild relatives is what creates transgenic crops. By introducing genes that either lower anti-nutrient molecules or increase the accumulation and absorption of micronutrients, transgenic breeding aids in bio-fortification. The introduction and overexpression of genes corresponding to micronutrients may help to make up for the deficits of micronutrients including zinc, iron, vitamin A, and proteins in various crops.

RNA Interference: A particular gene's transcription or translation is inhibited by the sequence-specific gene regulatory mechanism known as RNA interference (RNAi), which is fueled by a double-stranded RNA (dsRNA) molecule. RNAi has created new opportunities for crop development since its discovery. It is a more accurate, steady, productive, and superior tool than antisense technology. A platform for the incorporation of biotic and abiotic stress tolerance as well as the supply of high-quality food through bio-fortification and bio-elimination is provided by RNAi. It is frequently employed to improve crops' nutritional quality and remove pollutants and allergies from food.

Genome Editing: In order to produce transgene-free plants, sequence-specific nucleases (SSNs) are used in plant genome editing (GE) for targeted and stably inherited gene modification in the desired crop. Plant genome editing involves the employment of different SSN types, such as TALENs, ZFNs, and the CRISPR-Cas system. Cas9/13, RNA-guided DNA endonucleases that are used in CRISPR genome editing, are complexes that form at the target location for precise gene editing. Less genome editing was used for the bio-fortification of pulses and grains.



Top ranked crops based on production, consumption, micro nutrient deficiency, would most benefit from bio-fortification in India

Need for bio-fortification

The main objectives of bio-fortification are to lower the mortality and morbidity rates associated with micronutrient deficiencies as well as to improve the quality of life, productivity, and food security for the underprivileged populations of developing nations. For underdeveloped nations, bio-fortification is more crucial because it is inexpensive and simple to implement. People who lack access to other interventions may benefit from bio-fortification by receiving a variety of specific micronutrients. Poor farmers grow modern varieties of crops developed by agricultural research centers. In order to maximize output and profitability for farmers, the bio-fortification strategy aims to include the micronutrient-dense trait into as many released varieties as is practical.

Additionally, marketed surpluses of these commodities find their way into retail establishments where they are purchased by customers in both urban and rural locations. As it were, the flow is from rural to urban as opposed to complementary interventions that start in urban centers. The bio-fortification of staple crops is a top priority due to the fact that they are relatively affordable and available to the majority of people. Although the efficiency of bio-fortification is not comparable to food supplementation, it can still help reduce the micronutrient intake gap and increase the daily intake of vitamins and minerals throughout a person's life, and this may have significant impact on human health by reducing malnutrition (Bouis *et al.*, 2011).

Various bio-fortified crop varieties released by ICAR:

Sr.No.	Crop	Variety	Improved trait
1	Rice	CR Dhan 310	Protein (10.3 %)
		DRR Dhan 45	Zinc (22.6 ppm)
		DRR Dhan 48	Zinc 24.0 ppm
		DRR Dhan 49	Zinc 25.2 ppm
		Zinco Rice MS	Zinc 27.4 ppm
		CR Dhan 311 (Mukul)	Protein 10.1 %, Zinc 20.1 ppm
		CR Dhan 315	Zinc (24.9 ppm)
2	Wheat	WB 02	Iron (40.0 ppm), Zinc (42.0 ppm)
		HPBW 01	Iron (40.0 ppm), Zinc (40.6 ppm)
		Pusa Tejas (HI 8759) durum	Protein 12.0 %, Iron 41.1 ppm and Zinc 42.8 ppm
		Pusa Ujala (HI 1605)	Protein 13.0 %, Iron 43.0 ppm
		HD 3171	Zinc 47.1 ppm
		HI 8777 (durum)	Iron 48.7 ppm, Zinc 43.6 ppm
		MACS 4028 (durum)	Protein 46.1 ppm Iron 14.7 % Zinc 40.3 ppm
		PBW 752	Protein 12.4 %
		PBW 757	Zinc 42.3 ppm
		Karan Vandana (DBW 187)	Iron 43.1 ppm

		DBW 173	Protein (12.5 %), iron (40.7 ppm)
		UAS 375	Protein 13.8 %
		DDW 47	Protein 12.7 %, Iron 40.1 ppm
		PBW 771	Zinc 41.4 ppm
		HI 8802 (durum)	Protein 13.0 %
		HI 8805 (durum)	Protein 12.8 %, Iron 40.4 ppm
		HD 3249	Iron 42.5 ppm
		MACS 4058 (durum)	Protein 14.7 %, Iron 39.5 ppm, Zinc 37.8 ppm
		HD 3298	Protein 12.1 %, Iron 43.1 ppm
		HI 1633	Protein 12.4 %, Iron 41.6 ppm, Zinc 41.1 ppm
		DBW 303	Protein 12.1 %
		DDW 48 (durum)	Protein 12.1 %
3	Maize	Vivek QPM 9	Lysine 0.83 %, Tryptophan 4.19 %
		Pusa HM4 Improved	Tryptophan 0.91, % Lysine 3.62 %
		Pusa HM8 Improved	Lysine 4.18 %, Tryptophan 1.06 %
		Pusa HM9 Improved	Lysine 2.97 % Tryptophan 0.68 %
		Pusa Vivek QPM9 Improved	Provitamin-A (8.15 ppm), lysine (2.67 % in protein), tryptophan (0.74 % in protein)
		Pusa VH 27 Improved	Provitamin-A 5.49 ppm
		Pusa HQPM 5 Improved	Tryptophan 0.94% Lysine 4.25% Provitamin-A 6.77 ppm
		Pusa HQPM 7 Improved	Provitamin-A 7.10 ppm, Lysine 4.19%, Tryptophan 0.93%
		IQMH 201 (LQMH 1)	Lysine 0.73 %, Tryptophan 3.03 %
		IQMH 202 (LQMH 2)	Lysine 3.04 %, Tryptophan 0.66 %
		IQMH 203 (LQMH 3)	Lysine 0.77 %, Tryptophan 3.48 %
4	Pearl Millet	HHB 299	Iron 73.0 ppm, Zinc 41.0 ppm
		AHB 1200Fe	Iron 73.0 ppm
		AHB 1269Fe	Iron (91.0 ppm), Zinc (43.0 ppm)
		ABV 04	Iron (70.0 ppm), Zinc (63.0 ppm)
		Phule Mahashakti	Iron (87.0 ppm), Zinc (41.0 ppm)
		RHB 233	iron (83.0 ppm), Zinc (46.0 ppm)
		RHB 234	Iron (84.0 ppm), Zinc (46.0 ppm)
5	Finger Millet	VR 929 (Vegavathi)	Iron 131.8 ppm
		CFMV1 (Indravati)	Calcium (428 mg/100g), Iron (58.0 ppm), Zinc (44.0 ppm)
		CFMV 2	Calcium 454 mg/100g, Iron 39.0 ppm, Zinc 25.0 ppm
6	Little Millet	CLMV1	Iron 59.0 ppm, Zinc 35.0 ppm
7	Lentil	Pusa Ageti Masoor	Iron 65.0 ppm
		IPL 220	Iron (73.0 ppm), Zinc (51.0 ppm)
8	Ground nut	Girnar 4	Oleic acid 78.4 %
		Girnar 5	Oleic acid 78.5 %
9	Linseed	TL 99	Linoleic acid (58.9%)

10	Mustard	Pusa Mustard 30	Erucic acid 1.20 %
		Pusa Double Zero Mustard 31	Erucic acid (0.76 % in oil) and glucosinolates (29.41 ppm in seed meal)
		Pusa Mustard 32	Erucic acid 1.32 %
11	Soybean	NRC 127	Kunitz Tryptsin Inhibitor Free
		NRC 132	Lipoxigenase-2 free
		NRC 147	Oleic acid 42.0%
12	Cauliflower	Pusa Beta Kesari 1	Provitamin-A 8.0-10.0 ppm
13	Potato	Kufri Manik	Anthocyanin 0.68 ppm
		Kufri Neelkanth	Anthocyanin 1.0 ppm
14	Sweet Potato	Bhu Sona	Provitamin-A 14.0 mg/100g
		Bhu Krishna	Anthocyanin 90.0mg/100g
15	Greater Yam	Sree Neelima	Anthocyanin (50.0 mg/100g), Crude protein (15.4 %) and Zinc (49.8 ppm)
		Da 340	Anthocyanin (141.4 mg/100g), Iron (136.2 ppm) and Calcium (1890 ppm)
16	Pomegranate	Solapur Lal	Iron (5.6-6.1 mg/100g), Zinc (0.64-0.69 mg/100g) and Vitamin-C (19.4-19.8 mg/100 g)

(Source: Biofortified-Varieties-Book_V3_ICAR.)

Harvest plus

Harvest Plus and its partners fight hidden hunger worldwide by scaling up staple food crops that are bred to be rich in essential vitamins and minerals. The health, resiliency, and livelihoods of low-income consumers and smallholder farming households are sustainably improved by these bio-fortified, climate-smart crops, contributing to more wholesome and equitable food systems. HarvestPlus Vision for a world free from unrecognized hunger in which families, communities, and nations can realize their full potential. Its objective is to boost bio-fortification sustainably as a way to provide rural and low-income populations with a means of subsisting. Empower partners globally to combat hidden hunger. Harvest Plus aiming for One billion people will routinely consume nutrient-rich bio-fortified crops and foods by 2030, contributing to the accomplishment of the Sustainable Development Goal of eradicating all kinds of malnutrition. With the help of HarvestPlus 238 varieties of 11 bio-enhanced climate-friendly staples have been launched in 30 countries and hundreds more have been tested. 12.8 million Households grow and eat bio-enriched crops. Over 600 partnerships worldwide with government agencies, companies, NGOs, CSOs, and international organizations working to promote bio-fortification. In 2020 alone, 286,000 farmers (64% of women) were trained in crop production, production, processing and nutrition. Over 100 published scientific papers and over 40 research studies demonstrate the feasibility, effectiveness, and acceptability of bio-fortification.

Agriculture is the primary use of 60% of the country's land. The top five (5) crops in the country, in order of agricultural area, are rice, wheat, cotton, beans, and soybeans. In addition, sugar cane, rice, wheat, potatoes, and vegetables are the five (5) most prolific crops. Since 2011, Harvest Plus has been collaborating closely with public and private sector partners in India to produce bio-enriched crops, promote them, and create a value chain for bio-enriched seeds and crops in an effort to enhance nutrition and public health. The highest levels of government promote bio-fortification as a method of addressing widespread micronutrient deficiencies and associated detrimental impact on health.

In this nation, wheat is the most significant food grain, while iron pearl millet is one of the staple foods in the arid and semi-arid regions of India. The development of bio-fortified varieties of pearl millet received a significant regulatory push in 2018 when the Indian Council of Agricultural Research (ICAR) mandated minimum amounts of iron and zinc to be bred in national variations of the grain. ICAR, India's State Agricultural Universities (SAUs), the International Maize and Wheat Improvement Center (CIMMYT), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), seed companies, farmer organizations, and community organizations have all worked closely with Harvest Plus during its nearly nine years of operation in India. When consumed frequently, the iron pearl millet, zinc wheat, and iron lentil bio-fortified crops that these partners are promoting in India help reduce micronutrient shortages.

Accelerating access to these nutrient-dense crops and the meals made from them is a joint objective of Harvest Plus and our partners. This will increase food and nutrition security and enhance people's quality of life.

The Indian Council of Agricultural Research (ICAR), a close partner of Harvest Plus, recently released bio-fortified crops are as following:

- Zinc rice CR Dhan 315;
- Wheat varieties HI 1633 rich in protein, iron and zinc, HD 3298 rich in protein and iron, and DBW 303 and DDW 48 rich in protein;
- Ladhowal Quality Protein Maize Hybrid 1, 2 and 3 rich in lysine and tryptophan;
- CFMV1 and 2 of finger millet rich in calcium, iron and zinc;
- CLMV1 of little Millet rich in iron and zinc;
- Pusa Mustard 32 with low erucic acid;
- Girnar 4 and 5 of groundnut with enhanced oleic acid;
- Yam variety Sri Neelima and DA 340 with enhanced zinc, iron and anthocyanin content.

By utilizing public resources and taking the lead on policy, the Indian Council of Agricultural Research (ICAR), a close partner of HarvestPlus Governments, plays a crucial role in scaling up bio-fortification and encouraging engagement in the private sector.

To reach 1 billion people with nutrient-rich bio-fortified crops and foods by 2030, HarvestPlus and its partners are collaborating with governments in Africa, Asia, and Latin America/the Caribbean, as well as the commercial sector, NGO, and civil society partners. The CGIAR Program on Agriculture for Nurture and Health includes HarvestPlus (A4NH).

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BIOLOGICAL CONTROL OF PLANT PATHOGENS

Abhishek Singh*[1], Vivek Singh[2] and H. K Singh[1]

[1]Department Plant Pathology, ANDUAT, Kumarganj, Ayodhya, 224229 (U.P.) India

[2]Department Plant Pathology, CSAUAT, Kanpur (U.P.), India

*Corresponding author E-mail: abhishek45678903@gmail.com

Introduction:

Biological control is the use of natural or modified organisms, genes, or gene products, to reduce the effects of undesirable organisms such as plant pathogens and to favor desirable organisms such as crops (Research Briefings, 1987). The host plant's genetic alteration (genetic resistance) is included in this broad concept. The main focus of this chapter, however, will be on natural and engineered organisms as plant pathogen biological control agents. Antagonism is the generalised mechanism that biocontrol agents use to diminish plant pathogen survival or disease-causing activity. Antagonism is actively expressed opposition and includes antibiosis, competition and parasitism. Antibodies are used to control plant diseases biologically by killing existing pathogen inoculum, excluding the pathogen from the host plant, or inhibiting or displacing the pathogen after infection (Cook and Baker, 1983).

Disease suppressive soils:

Following the discovery of disease-suppressive soils, researchers looked at biological management of plant infections. These are soils where pathogens either cannot establish, develop but do not create disease, or establish and cause disease at first, but disease becomes less relevant as the crop is cultured. (Baker and Cook, 1974). Suppression of disease can be classified as either broad or specific. Specific suppression results from the activity of individual or select groups of microorganisms and is transferable between soils; general suppression results from the activity of the total microbial biomass in soil and is not transferable between soils; general suppression results from the activity of the total microbial biomass in soil and is not transferable between soils (Weller *et al.*, 2002). One of the best-documented examples of disease suppressive soils is the take-all decline phenomenon. Take-all root disease, caused by the soilborne fungus *Gaeumannomyces graminis* var. *tritici*, is a root and crown (basal stem) rot disease of wheat *(Triticum aestivum)* and barley *(Hordeum vulgare)* that occurs worldwide in temperate regions. Take-all decline happens naturally in some soils after 5 to 7 years of continuous wheat production with severe take-all disease and low yields. The sickness then becomes less severe, and yields begin to recover. Take-all reduction has been linked to increases in specific populations of microbes.

What makes biological control so common?

Growing public concern about the possible detrimental effects of some chemical pesticides on human health and the environment has sparked scientific interest in biological control of plant diseases. There is also a need to manage diseases for which there are now no or just partial controls because the host has little or no genetic resistance, crop rotation is difficult or not economically possible, or reliable, cost-effective chemical controls are unavailable. For example, no practical or economical chemical control for crown gall disease was replaced when biological control with *Agrobacterium radiobacter* K84 was developed (Cook, 1993). Furthermore, compared to traditional chemical pesticides, registered biological controls have shorter reentry times and preharvest intervals. Growers will have more flexibility in balancing their operational and pest management practises as a result of this. (McSpadden Gardener and Fravel, 2002).

Difficulties in biological control:

Despite the fact that a variety of microorganisms have been shown to protect crop plants from disease in the lab, commercial development of several antagonists has been delayed by uneven effectiveness across field locations and seasons. Many reasons have been blamed for differences in biological control agent performance. Compatibility of the host plant and the biocontrol agent due to host plant genotype, agricultural practises, mutation of the biocontrol organism resulting in loss of effectiveness, pathogen resistance to biocontrol mechanisms, vulnerability of the biocontrol agent to pathogen defence mechanisms, and effects of the environment on the biocontrol agent's survival and effectiveness are just a few examples.

Antagonists are living creatures, and they will only be active if the environment supports their growth and reproduction, whether they are administered directly to the host plant, to field soil, or to greenhouse growth medium. A change in climatic conditions during the growing season may have a significant impact on a biocontrol agent's ability to control a plant disease, yet the same environmental changes may have little impact on the pathogen's ability to be controlled by a chemical pesticide. Antibody inocula preparation and storage, as well as antagonist application, have stringent restrictions. Biocontrol agent inocula cannot normally be stored at the severe temperatures required for storing a wettable powder fungicide. Biocontrol agent inocula cannot normally be stored at the severe temperatures required for storing a wettable powder fungicide. Furthermore, because antagonist inocula has a shorter shelf life than conventional pesticides, producers cannot stockpile significant quantities of antagonist inocula for subsequent use.

Antagonism mechanisms:

Bacteria, fungus, nematodes, protozoa, and viruses are examples of antagonists employed for biological control of plant diseases. Antibodies, with a few exceptions, are rarely pathogen specific; instead, their action on plant pathogens is purely accidental (Cook and Baker, 1983). An antagonist that colonises roots aggressively and suppresses a wide range of microorganisms, for example, may protect roots from infections, but the action against any particular pathogen is likely coincidental. There are antagonists, however, who have a parasitic relationship with their microbial host. Plant infections are inhibited by antagonists through antibiosis, competition, and parasitism. These systems do not conflict with one another. An antagonist may employ numerous methods to harm a plant pathogen, or may employ one mechanism against one type of pathogen and another against another. For example, control of *Botrytis* on grapes *(Vitus)* with the fungal antagonist *Trichoderma* involves competition for nutrients and parasitism of sclerotia. Both mechanisms contribute to the suppression of the pathogen's capability to cause and perpetuate disease (Dubos, 1987).

Antibiosis:

The suppression or killing of one organism by a metabolite produced by another organism is known as antibiosis. Antagonists have the potential to develop potent growth inhibitory chemicals that are effective against a wide range of microbes. Antibiotics with a broad spectrum of activity are known as broad-spectrum antibiotics. However, other metabolites, such as bacteriocins**,** are solely efficient against a specific type of microbe. . The bacterial antagonist *A. radiobacter* K84 produces agrocin 84, a bacteriocin that is effective only against bacteria that are closely related to *A. radiobacter*, such as the crown gall pathogen *A. tumefaciens*. Because their antibiotics limit the growth or germination of other bacteria, antagonists that manufacture antibiotics have a competitive advantage in occupying a niche and obtaining substrates as food sources.

Antibiosis is a useful process for protecting germinating seeds. For example, the bacterial antagonist *Pseudomonas fluorescens* Q2–87 can protect wheat roots against the take-all pathogen, *G. graminis* var. *tritici*, when coated onto seed. The bacteria increase in the rhizosphere when the seeds germinate, feeding on exudates from the roots. The rhizosphere is a thin coating of dirt that adheres to the root after loose material has been removed by shaking, and it is directly influenced by compounds that the root exudes into the soil solution. The antibiotic 2,4-diacetylphloroglucinol, which is produced by *P. fluorescens* Q2–87, is effective against the take-all pathogen in minute quantities and has been recovered from the wheat rhizosphere (Bonsall et al, 1997). Antibiotics' efficiency in soil, on the other hand, can be varied since they can bind to charged clay particles, be destroyed by microbial activity, or be washed away from the rhizosphere by water.

Antibiotics:

Many antagonists may not create antibiotics to target a specific pathogen, and antagonists may not produce the same antibiotics under different environmental conditions. Some antagonists make a variety of bioactive chemicals that are useful against a variety of plant diseases. The bacterial antagonist *P. fluorescens* Pf- 5 produces multiple antibiotics, including pyoluteorin, pyrrolnitrin, and 2,4- diacetylphloroglucinol. Pyoluteorin inhibits *Pythium ultimum*, a common cause of seedling disease in cotton *(Gossypium hirsutum);* however, it has little effect on other cotton seedling pathogens, such as *Rhizoctonia solani, Thielaviopsis basicola,* and *Verticillium dahliae* (Howell and Stipanovic, 1980). Pyrrolnitrin inhibits *R. solani, T. basicola,* and *V dahliae,* but is not active against *P. ultimum* (Howell and Stipanovic, 1979). Examples of bacterial biological control agents that produce antibiotics include *Bacillus, Pseudomonas,* and *Streptomyces*. Fungal antagonists that produce antibiotics include *Gliocladium* and *Trichoderma*.

Enzymes and volatile compounds:

Several volatile substances have a role in biocontrol of plant pathogens. These include ammonia (produced by the bacterial antagonist *Enterobacter cloacae* against the plant pathogens *P. ultimum, R. solani,* and *V dahliae*), alkyl pyrones (produced by *T. harzianum* against *R. solani*), and hydrogen cyanide (produced by *P. fluorescens* against *T. basicola,* which causes black root rot). Although numerous enzymes are involved in parasitism's biocontrol mechanism, certain enzymes are only involved in antibiosis. For example, the fungal biocontrol agent *Talaromyces flavus* Tf1 is effective against Verticillium wilt of eggplant *(Solanum melongena)*. *Talaromyces flavus* produces the enzyme glucose oxidase; hydrogen peroxide is a product of glucose oxidase activity and kills microsclerotia of *Verticillium* in soil (Fravel, 1988). The enzyme alone does not kill microsclerotia.

Competition:

Competition occurs when two or more organisms compete for the same food (carbon and nitrogen) or mineral source, or for a niche or infection site. Because of its faster growth or reproductive rate, or because it is more effective in collecting nutrients from food sources, the successful competitor has an advantage over the others. *Pseudomonas fluorescens* produces a siderophore, pseudobactin, which deprives pathogens such as *Fusarium oxysporum* of iron. Siderophores are extracellular, low-molecular-weight microbial molecules with a high affinity for ferric iron (attraction). Chlamydospores of *F. oxysporum* require an exogenous source of iron to germinate. Although *F. oxysporum* also produces siderophores, the siderophores of *P.*

fluorescens are more efficient in binding iron. If *P. fluorescens* is active in soil, chlamydospores of *F. oxysporum* remain dormant and cannot germinate due to low iron conditions.

Another example of employing competition to control a plant disease is biological control of annosus root rot in conifers. Annosus root rot is caused by the fungus *Heterobasidion annosum,* which can survive for many years in stumps and logs, and causes extensive damage in managed forests or plantations of pure stands. To control annosus root rot, freshly cut stumps are inoculated with the fungal antagonist *Phlebia gigantea.* The mycelium of *P. gigantea* physically prevents *H. annosum* from colonizing stumps that it would use as a food base for attacking young pine *(Pinus)* trees (Cook and Baker, 1983).

Cross protection is a type of competition in which an avirulent or weakly virulent pathogen is employed to guard against infection by a more virulent pathogen of the same or closely related species. In virology, this phrase was used to explain situations in where one virus infecting a cell reduced the possibility of a second virus damaging the cell. Cross protection has no host reaction (see induced systemic resistance) and is not transmissible (see hypovirulence). *Cucumber mosaic virus* (CMV) pathogenicity can be reduced in some vegetable crops by inoculating with CARNA 5, a small satellite-like self-replicating RNA molecule. However, it is important to remember that weakly virulent strains can become more virulent or there may be unexpected synergistic effects that enhance disease. For example, CARNA 5 reduces disease caused by CMV in squash *(Cucurbita pepo)* and sweet corn *(Zea mays),* but enhances disease severity caused by CMV in tomato *(Lycopersicon esculentum)* (Cook and Baker, 1983).

Parasitism:

The feeding of one organism on another is known as parasitism. Parasitism can be used to reduce sclerotia inoculum or prevent root rots as a biocontrol mechanism, but it may be less effective in protecting germinating seeds because establishing a parasitic relationship between the antagonist and pathogen may take longer than the time it takes for the pathogen to infect the seed. Mycoparasites are fungi that parasitize other fungi. The fungus's antagonistic parasitism The fungal host (plant pathogen) is frequently detected from a distance in the early stages of *Trichoderma.* The hyphae of *Trichoderma* grow toward a chemical stimulus given by the pathogen. This is followed by recognition, which is physical or chemical in nature, and attachment of *Trichoderma* hyphae to the host fungus that coils around the pathogen hyphae. *Trichoderma* produces lytic enzymes that degrade fungal cell walls. In some cases, cell-wall-degrading enzymes and antibiotics act synergistically in the biocontrol process (Chet *et al.,* 1998). Examples of mycoparasites include *T. hamatum, T. harzianum, T. koningii, T. virens, T. viride, Pythium nunn,* and *P. oligandrum.*

Other biological control mechanisms

Hypovirulence:

When a hypovirulent (weakly virulent) strain of a fungal pathogen fuses (anastomoses) with a virulent strain of the pathogen, the hypovirulent state is transmitted to the virulent strain, resulting in biological control by hypovirulence. The fusing of contacting hyphae is known as anastomosis, and it indicates vegetative compatibility. The pathogen is infected with one or more dsRNAs of viral origin, resulting in transmissible hypovirulence. The biocontrol of chestnut blight caused by the fungal pathogen *Cryphonectria parasitica* with hypovirulent strains of the fungus is a classic example of hypovirulence.

Induced systemic resistance:

Induced systemic resistance (ISR) in the host plant can be caused by nonpathogenic plant-growth-promoting rhizobacteria (PGPR) colonisation. ISR is a plant-mediated biocontrol technique in which the pathogen and the biocontrol agent do not come into touch. In ISR, host plant defences are boosted and plants are given systemic protection. Jasmonic acid and ethylene influence the amount of host reaction. (van Loon *et al.*, 1998). Because many PGPR also produce antibiotics, iron-chelating siderophores, and lytic enzymes, their capacity to suppress illness could be due to a combination of mechanisms. PGPR may play a role in biological disease control, plant growth promotion, or a combination of the two. Commercial crop protection solutions are available in a variety of strains or combinations of strains (McSpadden Gardener and Fravel, 2002).

Increased growth response:

Biological control microorganisms, such as PGPR and several fungal biocontrol agents, have been linked to increased plant growth. Increased host plant development is often attributed to a reduction in viable inoculum of undiscovered diseases, such as root-infecting Pythium species, which produce very minor vigour or yield declines. In other circumstances, greater plant growth, especially in the absence of pathogens, could be attributable to microbial-derived plant-growth-promoting chemicals (Chet, 1993).

Biocontrol product delivery, application, and formulation for plant diseases:

Biocontrol chemicals can be applied in a variety of ways, including foliar sprays, soil or soilless mix treatments, seed treatments, root dips, and postharvest drench, drip, or spray applications to fruit. Dusts, dry and wettable powders, dry and water-dispersible granules, and liquids are among the commercially available product formulations (Desai *et al.*, 2002). The most common purpose of foliar sprays is to protect above-ground plant sections from foliar pathogens. A typical method of biological control of soilborne diseases is to incorporate antagonist inocula into the soil. The adversary is usually introduced in a latent state, frequently with a food base, so that it can establish itself fast in the soil. In the horticulture business, commercially produced soilless mixes with one or more biological control agents created in the mixes have been offered. Pathogen populations are suppressed by the mixtures when they are exposed to a specific set of environmental circumstances. Adding organic supplements to greenhouse mixes or field soil, such as ground shrimp, crab shells, or bean leaf powder, has also been used to promote the growth of antagonistic organisms at the expense of plant pathogens.

Treating seeds with antagonists is one of the more successful techniques of introducing biocontrol agents into an agricultural system. This method provides soilborne pathogen antagonists as close to the target as possible. Before the pathogen may attack the seed, seed treatments deposit the antagonist in the infection court (the seed coat surface) at planting. Formulated products can be applied as powders or liquids directly at the time of planting, eliminating the need for stickers. Antagonists can also be applied to seed as dry powders or liquid-based formulations. Biocontrol agents on seeds are given additives to help them survive longer. After the seeds have dried, keep them with the antagonists until planting time. In some biocontrol products, bacterial antagonists and chemical fungicides are applied in combination to seeds (Warrior *et al.,* 2002).

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FORWARD AND BACKWARD LINKAGES IN FARMER PRODUCER ORGANIZATIONS

S. Moghana Lavanya* and K. Mani

Department of Agricultural and Rural Management,

Tamil Nadu Agricultural University, Coimbatore

*Corresponding author E-mail: smoghana@tnau.ac.in

Agriculture in India:

Small and marginal farmers (less than 2 ha) constitute the major farming population. About 52 per cent of the countries work force is engaged in agriculture and depends totally as source of livelihood, but their contribution in the total GDP is only 14 per cent, reflecting disguised unemployment. Due to shrinking of land area, less accessibility of improved technologies and services leads to low production and productivity Another major problem faced by Indian farmers is market inefficiency which reduces the producers share in consumer's rupees giving less remunerative prices to the farmers for their produce.

A feasible answer for achieving economies of scale in production and marketing in a smallholder dominated agrarian situation is collective action. Different farmer's collectivization models had been tried and tested in India. The emerging, innovative, and participative models is the creation of Farmers Producers Organization (FPO). The concept of changing the perspective on Agriculture to Agribusiness led to introduction of concept of Farmer Producer Company (FPCs) under by Indian Companies act, 1956 in 2003. The concept of farmer producer companies in India is a very recent development. Farmers form a group and combine their share capital, register as a company, employ a professional to run the company and do value addition by creating forward and backward linkages, wherever possible. It enables the member-farmers to reap the benefits of economies of scale in purchase of inputs, processing, and marketing of their produce. Forming a FPO can also provide the member-farmers access to timely and adequate credit and provide linkages to markets.

The three major implementing agencies for FPCs are Small Farmer Agri-business Consortium (SFAC), Rural development bank – National Bank for Agriculture and Rural Development (NABARD), and National Cooperative Development Corporation (NCDC).The Departmentt of agriculture and horticulture of state governments and NGOs are also involved in establishment of FPOs. Each agency has its own criteria for selecting the project/promoting institution to support.

Once the idea to forma FPO is finalized the Information about FPO is informed to all families of the village. All interested farmers can become members of the FPO. Each member will have one vote in the company, irrespective of their share. Government or its nominated bodies help to fund and guide for its formation. Government also assists the FPOs in training farmers, administrational activities, storing farm produce and adding value to it. Need-based seed capital is given to FPO to enable to borrow the required capital and working capital from financial institutions for the implementation of the project proposal after it has been appraised and accepted as viable.

Farmer Produce Organizations involves grouping producers especially small and marginal farmers to form an effective alliance for addressing the challenges such as improved access to investment, technology, inputs, and markets. Purchase of inputs, access to farm machinery and remunerative prices are the main issues faced by the farmers. FPOs help in purchase and supply of inputs at a better cost also ensuring timely availability by understanding the localized needs of their members.

Producer company professionals will be accountable to the board of directors of the producer company, which will include some farmers. General body of the farmers / members will have the ownership of the producer company, through an annual business plan and budget. Membership is given to farmers keeping their needs in mind and not necessarily based on the crop that they produce to ensure that there is round the year business for the FPO. It must have minimum 50 shareholding members at the time of registration and can be increased over a period of 3 years to a sustainable level.

FPO’s are engaged in producing value added products for their benefit and also for the people. Innovative value-added activities developed on farms or at agricultural experiment stations, either in the kind of product or in the technology of production are sources of national growth (*http://www.agmrc.org*). FPOs offer small farmers to participate in the market more effectively and help to enhance agricultural production, productivity, and profitability (Stockbridge *et al.*, 2003). For every FPO, it is mandatory to develop strong forward linkages with wholesalers, retailers and exporters.

Region wise scenario of FPOs under NABARD

NABARD provides financial support to the FPOs only through project mode through two financial products. First is lending the FPOs for contribution towards share capital on matching basis (1:1 ratio) to enable the FPO to access higher credit from banks. This is a loan without collateral which will have to be repaid by the FPO after specified time. The maximum amount of such assistance is Rs.25 lakh per FPO with a cap of Rs.25, 000 per member. Next is credit support against collateral security for business operations. Credit support is available for business activities and creation of assets like building, machinery, equipment, specially designed vehicles for transportation etc. and/or working capital requirements including administrative and other recurring costs connected with the project as composite loan. Capital expenditures like purchase of land, vehicles for general transportation & personal use, etc., will not be considered for support. The details of region wise FPO registered under NABARD is given in the Table 1.

Table 1: Region wise list of FPO registered in NABARD

Region	No. of FPOs			No. of FPOs registered as		
	Formed	Registered	Company	Society	Cooperative	Others
Central	760	**386**	245	16	125	0
Eastern	1096	**416**	264	0	14	138
NE Region	99	**70**	10	39	20	1
Northern	538	**329**	215	22	92	0
Western	407	**224**	156	3	65	0
Southern	1104	**619**	575	38	6	0
Total	4,004	**2,044**	1,466	118	322	139

(Source: https://www.nabard.org)

It could be observed from the above table that Southern region occupied the first position having 619 registered FPOs. In southern region especially, Government of Karnataka is providing financial support for the infrastructural facilities of FPOs up to 90 per cent. Selected Resource nstitutions (RI) to assist and organize the working of FPOs and to provide them management support for 3 years. RIs engage the Local Resource Persons (LRP) to help the farmers with necessary inputs and keep tracking the progress of the activities in field also provided with technical inputs by the State Universities.FPOs are granted with licenses in seeds, fertilizers and pesticides for storage and sales. The FPOs will be provided with APMC commission agent license and trader license with priority go-down space in APMCs. This might be the reason for having more number of FPO registered in Karnataka. Tamil Nadu having 170 FPOs registered under NABARD. It gives financial support to the FPOs upto 100 percent. Even though NABARD was ready to give financial support to the FPOs, the farmers have been lagging about FPOs organization and its concepts. Next to Karnataka and Tamil Nadu more number of FPOs was found in Madhya Pradesh, West Bengal, Rajasthan and Gujarat.

State wise scenario of FPO under Small Farmers Agribusiness Consortium (SFAC)

SFAC operates a credit guarantee fund to mitigate credit risks of financial institutions which lend the farmer producer companies (registered as producer company under Part IX-A of companies' act) without collateral. This helps the FPCs to access credit from mainstream financial institutions for establishing and operating businesses. SFAC provides matching equity grant up to Rs.10 lakhs to the FPCs to enhance borrowing power, and thus enables the entities to access bank finance. Government of India provides budgetary support to SFAC for its equity grant and credit guarantee fund scheme for the farmer producer company. Integrated Scheme for Agricultural Marketing (Ministry of Agriculture, Government of India) helps in creation of storage and other agricultural marketing infrastructure. The details of state wise FPOs registered under SFAC is given in Table 2.

Table 2: State wise list of FPO registered in SFAC

Sr. No	State	No. of FPO	Percentage to total
1	Andhra Pradesh	7	0.89
2	Arunachal Pradesh	2	0.25
3	Assam	12	1.53
4	Bihar	24	3.06
5	Chattisgarh	23	2.94
6	Delhi	4	0.51
7	Goa	2	0.25
8	Gujarat	20	2.55
9	Haryana	23	2.94
10	Himachal Pradesh	5	0.64
11	Jammu & Kashmir	2	0.25
12	Jharkhand	8	2.81
13	Karnataka	117	14.92
14	**Madhya Pradesh**	**135**	**17.21**
15	Maharashtra	85	10.84
16	Manipur	4	0.51
17	Meghalaya	3	0.38
18	Mizoram	1	0.12
19	Nagaland	2	0.25
20	Odisha	41	5.22
21	Punjab	7	0.89
22	Rajasthan	40	5.10
23	Sikkim	29	3.69
24	**Tamil Nadu**	**44**	**5.61**
25	Telangana	20	2.55
26	Tripura	4	0.51
27	Uttar Pradesh	34	4.33
28	Uttarakhand	7	0.89
29	West Bengal	68	8.67
	Total	**784**	**100.00**

(Source: http://sfacindia.com)

It could be observed from the above table that Madhya Pradesh occupied the first position having 135 FPOs followed by Karnataka 117 FPOs. Tamil Nadu is having 44 FPOs registered under SFAC and other states like Maharashtra, West Bengal and Rajasthan were having more number of FPOs after Madhya Pradesh and Karnataka. SFAC have more guidelines to start FPC and documentation check is done every financial year. This might be considered as one of the reasons for the low interest by the people of our country to register FPC under SFAC.

Active FPO in Tamil Nadu

Table 3: List of Active Farmer Producer Company in Tamil Nadu

Sr. No	District	FPO under NABARD	FPO under SFAC	Total number of FPO	Percentage to Total
1	Ariyalur	8	2	10	4.67
2	Coimbatore	7	3	10	4.67
3	Cuddalore	5	1	6	2.80
4	Dharmapuri	5	1	8	2.80
5	Dindugal	12	2	14	6.54
6	Erode	6	1	7	3.27
7	Kanchipuram	5	1	6	2.80
8	Kanyakumari	4	1	5	2.33
9	Karur	3	-	3	1.40
10	Krishnagiri	5	2	7	3.27
11	Madurai	6	-	6	2.80
12	Nagapattinam	7	2	9	4.20
13	Namakkal	4	2	6	2.80
14	Nilgris	3	1	4	1.86
15	Perambalur	7	1	8	3.73
16	Pondicherry	3	1	4	1.86
17	Pudhukottai	4	1	5	2.33
18	Ramanadhapuram	5	1	6	2.80
19	**Salem**	**5**	**3**	**8**	**3.73**
20	Sivaganga	7	2	9	4.20
21	Thanjavur	5	2	7	3.27
22	Theni	3	1	4	1.86
23	Thoothukudi	8	1	9	4.20
24	Trichy	6	2	8	3.73
25	Tirunelveli	8	-	8	3.73
26	Tiruppur	4	2	6	2.80
27	Tiruvallur	6	1	7	3.27
28	Tiruvannamalai	4	2	6	2.80
29	Vellore	3	-	3	1.40
30	Villupuram	8	1	9	4.20
31	Virudhunagar	9	3	12	5.60
	Total	**170**	**44**	**214**	**100.00**

Nearly 92 per cent of operational holdings in Tamil Nadu were small and marginal holdings with limited capacity in mobilizing credit, adopting latest technologies, and adding value to their agricultural produce. To avail these benefits and to increase the income of the farmers, Government of Tamil Nadu has announced an innovative programme for organizing small and marginal farmers into farmer producer groups which was federated into farmer producer organizations and also to promote collective farming for credit mobilization, better adoption of technology and to facilitate effective forward and backward linkages in the budget 2017-2018. Farmer producer group were given a corpus fund of Rs.5 lakhs besides channelizing grants and credit available to farmer producer organizations from NABARD and Small Farmer Agribusiness Consortium.

A total allocation of Rs.100 crores during the year 2017-2018. The government has planned to scale up to benefit 40 lakhs farmers over the next five years in Tamil Nadu .The details of Farmer Producer Company in Tamil Nadu is provided in Table 1.3.At present ,totally 214 farmer producer companies in Tamil Nadu. Among them, Dindugal ditrict has more number of farmer producer companies (6.54 per cent) followed by both Ariyalur and Coimbatore withs ten number of FPCs (4.67 per cent) when compared to other district. Salem district have eight FPCs.

Backward and Forward linkages of Farmer Producer Companies

The performance and viability of farmer producer companies are determined by governance structure, network with external agencies, access to funds and technology, member–producers' contribution to business and financial performance. These companies can become viable if they have orientation to marketing of members' produce and business expansion. The importance of linkages for an FPC could be approximated by the percentage of inputs purchased from other industries for backward linkages such as seeds, fertilizers, nursery etc and the percentage of finished products sold to markets for forward linkages such as processed milk, oils, treated seeds, processed grains and other value added products. A forward linkage is the process of how a company sells its goods, products or supplies. Marketing is a process that involves a product or service's attributes, pricing, distribution, and promotion. All of these activities must work together to assure successful marketing. The farmer producer companies sold the value added products to the retailers and in a lesser extent sold the products directly to the consumers. The retailers purchased the products directly from the premises of FPCs.The FPCs made the products based on the orders received.

Figure 1: Backward and Forward linkages of Farmer producer companies

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http://sfacindia.com

https://www.nabard.org

http://www.thedialogue.co/india-promote-farmers-producers-organisations/

POSTHARVEST DISEASE MANAGEMENT OF FRUITS AND VEGETABLES

Manasranjan Rout[1], Tapas Ranjan Das[1],
Lipilipsa Priyadarshini[1] and Aurobindo Mohanta[2]
[1]Department of Plant Pathology Science
[2]Department of Agronomy
Faculty of Agricultural Science (IAS), Siksha O Anusandhan (Deemed to be University)
*Corresponding author E-mail: manasrout0001@gmail.com

Introduction:

In comparison to cereals, pulses, and oil seed crops, fruits and vegetables are regarded as perishable crops. The majority of them have a high moisture content (between 70 and 95 percent water), are typically large (5 to 5 kg), have a high respiration rate, and typically have a soft texture, all of which favour the growth and development of various diseases brought on by microorganisms between the times of harvest and consumption. According to estimates, postharvest losses of fruits and vegetables in underdeveloped nations range from 30 to 50 percent or more (Salunkhe and Desai, 1984). Because fruits and vegetables are living things, factors such as the current temperature, relative humidity, atmosphere during and after harvest, and the type and severity of insect or microbial infestation all have an impact on how long they can be sold. They degrade during storage because to moisture loss, pathogen-caused decay, rodent damage, loss of energy from storage, and loss of minerals and vitamins (Desai and Pathak, 1970; Pathak, 1997), a loss in quality due to physiological abnormalities, fiber development, greening (potatoes), root growth, sprouting, rooting, shoot growth, and seed germination, in addition to physical losses brought on by pest and disease attack. Post-harvest losses are also brought on by the contamination of food by mycotoxins, which are produced by plant tissues in response to fungi attack.

Diseases exacerbated by postharvest pathogens

Many pathogens, including fungus and bacteria, are to blame for the diseases that affect fruits and vegetables. However, it is widely recognized that bacteria like *Erwinia* and *Pseudomonas* and fungi like *Alternaria, Aspergillus, Botrytis, Colletotrichum, Diplodia, Monilinia, Penicillium, Phomopsis, Rhizopus, Mucor*, and *Sclerotinia* are the main causes of postharvest losses (Barkai Golan, 2005; Sharma *et al.*, 2009). The majority of these organisms are weak pathogens that can only enter produce that has been harmed. Physical damage is the main reason for the losses and plays a significant role in postharvest degradation. Injuries of all kinds can occur both before and after the collection of produce. Weather, insects, birds, rats, and farm equipment can all inflict harm. Fruits are frequently hurt when they are dropped onto a hard surface before, during, or after packing, but the damage is frequently not immediately noticeable. Later, bruising may also occur, although it just appears on the outside (as on apples), or it may only be noticeable when the item is peeled (e.g., potatoes). The overstocking of bulk product in warehouses or the overfilling of the packaging can both cause compression bruising (e.g, grapes). Underfilled packs are susceptible to vibration damage, especially when travelling over long distances by road. Various bacteria attack the harmed product, causing a gradual degradation that could spread throughout the entire crop (Snowdon, 1990).

Postharvest infection

Numerous fungi that result in significant produce loss are difficult to enter produce with an undamaged peel, but they can easily enter through any crack in the peel. Even though the harm is little, the crop's diseases can nevertheless flourish there thanks to it. Additionally, numerous microbes enter the body through the cut stem, and stem-end rots are significant postharvest spoilages of many fruits and vegetables (Barkai-Golan, 2005). For example, postharvest infection by *Sclerotina* and *Colletotrichum* is very common in many fruits through direct penetration of the peel. The infection of postharvest produce is caused by the infection to the different parts of the plants, such as floral infection, stem-end infection, and quiescent infection.

Factors affecting the development of infection

The surrounding environment of the produce always plays an important role in the development of infection by the pathogens and in the subsequent postharvest wastage of the produce. The high temperature and high humidity favor the development of postharvest decay, and chilling injury generally predisposes tropical and subtropical produce levels and the correct humidity can restrict the rate of postharvest decay by checking the rate of ripening or senescence, repressing the growth of the pathogen, or both (Barkai-Golan, 2005). In addition, several other factors also affect the rate of development of infection in fruits and vegetables. For example, the fruit peel, which acts as a selective medium, is generally attacked by several fungi. Many vegetables have a pH>4.5 and consequently bacterial rots are much more common in vegetables. Ripening fruits are more susceptible to wastage than immature fruits. Hence, treatments that slow down the rate of ripening (e.g., low temperature) will also retard the growth of decay organisms. Vegetables with the underground storage organs, for example, potato, cassava, yam, sweet potato, etc., are capable of forming layers of specialized cells (wound periderm) at the site of the injury, thus restricting the development of postharvest decay. During commercial handling of potato, periderm formation is promoted by 10–14 days storage at 7–15°C and 95% RH, a process known as curing. A type of curing process (possible by desiccation) has been shown to reduce the wastage of oranges by *Penicillium digitatum*. When the fruits are held at higher temperature (30°C) and humidity (90%) for several days, the orange peel becomes turgid and lignin are synthesized in the injured flavedo tissue, which affects the entry of microorganisms and thereby the decay.

Management of postharvest diseases of fruits and vegetables

Three main strategies are used as the fundamental ways for the control of postharvest illnesses in fruits and vegetables: (a) infection prevention, (b) infection eradication, and (c) pathogen spread prevention in the host tissue. Maintaining fruit free of disease or symptom until it is marketed or consumed is the primary goal of postharvest fruit disease management. As a result, management tactics should focus on preventing, eliminating, and postponing illness signs when fruits and vegetables are in transit and storage. (Sharma and Alam, 1998; Barkai-Golan, 2005). Postharvest Disinfection of Fruits and Vegetables To manage postharvest diseases of fruits and vegetables, the treatments are broadly divided into three groups, that is, physical, chemical, and biological. The effectiveness of treatment depends on the ability of the treatment or agent to reach the pathogen, the level and sensitivity of the infection, and the sensitivity of the host produce. The various methods of postharvest disease control of fruits and vegetables have been described briefly in the following sections.

1. Physical treatments

Different physical treatments, such as heat removal and low temperature storage, high temperature treatments, magnetic fields, and radiation, may be used to control the postharvest diseases of fruits and vegetables. Sound, ultrasound, radio, microwave, infrared, visible light, ultraviolet (UV), X rays, gamma rays, and cathode ray spectra are some of the different radiations. Some have a strong fungicidal impact, whereas others don't work as well (Eckert and Sommer, 1967). A couple of these have maybe been employed in postharvest treatments of fruits and vegetables, and they are briefly detailed.

1.1 Use of Gamma irradiation

The deep-rooted infections can be inactivated by gamma irradiation by penetrating the produce. Due to the infrequent occurrence of cell division in immature tissues, mature fruits are relatively resistant to radiation damage (Johnson *et al*., 1990). When compared to the dose needed for disinfection (75-300Gy), the doses needed to eradicate infections range from 2000 to 3000Gy, with some cases requiring as little as 1000Gy and others as much as 6000Gy (Barkai-Golan *et al.*, 1977). The radiation dose necessary for disease control is typically detrimental to fruit quality. Gamma irradiation can successfully prevent *lasiodiplodia*, which is the root cause of stem-end rot in mango fruits. In several fruits and vegetables, gamma irradiations have been quite effective in preventing postharvest infections.

Palou *et al*. (2007) used sodium carbonate, which is an alternative to synthetic fungicides to control citrus postharvest disease because it is inexpensive and can be used with a minimal risk of damage to the fruits. A combination of sodium carbonate with an X-ray irradiation dose of 0.875 kGy is more effective in controlling *P. digitatum* and *Penicillium italicum* compared to a single treatment. Several investigations have shown the inhibitory nature of nanosilver particles (NA) associated with sterilization (Jung *et al*. 2014). At a dose of 1 kGy, gamma irradiation had no antifungal effect, but when used in combination with NA or nanosized silica silver (NSS) at concentrations more than 1 g L/1, the same dose of gamma rays had the greatest antifungal effect. The combination of irradiation and cold storage, according to a study, is also promising for preventing postharvest infections. Comparing apples maintained at 0°C for 4 months to those kept at 20°C, gamma irradiation significantly reduced the growth of *Colletotrichum acutatum* on them (Kim *et al.,* 2011). Recently, it was demonstrated that *P. expansum* spore germination may be completely prevented with a 0.6 kGy dose of gamma radiation when combined with storage at 1°C, with no noticeable physical changes to apples (Mostafavi *et al.*, 2012).

1.2 Use of low temperature

Utilizing low temperatures is thought to be crucial in preventing deterioration in a variety of fruits and vegetables. Low temperatures may inhibit the growth of diseases, but they also delay fruit ripening. Controlling temperature is crucial for preventing disease incidence, physiological degradation, moisture loss, and shriveling. For this reason, cooling can be thought of as an addition to fungicidal treatments in a number of fruits and vegetables with many commodities (Barkai Golan, 2005). Every 10°C rise in temperature between 0 and 30°C leads to a two- to threefold rise in metabolic activity. In general, it is advised to keep produce at the coolest temperature feasible without endangering the host. With many fruits and vegetables, the lowest desirable temperature is just above the freezing temperature. Certain varieties of apples, pears, plums, peaches, and grapes can thus be stored between 0 and -2°C. It is commonly observed that apples and pears stored at slightly below 0°C are attacked by *B. cinerea, P. expansum, and Cladosporium*. The pathogenic growth of most fungi, however, is completely stopped at temperature near 0°C. *Rhizopus* spp. was found to be highly susceptible to chilling injury near 0°C (Barkai-Golan, 2005).

2. Postharvest chemical treatments

Produce injuries caused during harvesting, processing, and packaging are the main entry points for postharvest wound infections; chemically treating wounds will significantly reduce deterioration in storage. Injuries are caused when the crop is chopped off from the plant, or cuts are purposefully made while being handled, such stem cuts on banana hands or petiole cuts on celery destined for export. Other potential infection sites include the host's natural openings, such as lenticels and stomata, whose susceptibility to infection is heightened by injury or after a thorough water wash. The pathogenic microorganisms gathered in all those locations should be disinfected effectively. (Eckert, 1978; Eckert and Ogawa, 1985). Different chemicals, such as biphenyl (diphenyl), SOPP, thiabendazole, carbendazim, dicloran, iprodione, prochloraz, and ridomil, have been used to control postharvest decay in devel fruits and vegetable successfully (Table 5). Aluminum containing salts provided strong inhibition of all the tested pathogens (*Alternaria solani*, *B. cinerea*, *Fusarium sambucinum*, *Pythium sulcatum*, and *R. stolonifer*) with minimal inhibitory concentration of 1–10mM. Aluminum chloride and aluminum sulfate are generally the most effective, inhibiting the mycelial growth of pathogens by as much as 47% and 100%, respectively, at a salt concentration of 1mM. When applied at 5mM, aluminum sulfate also provided 28% and 100% inhibition of dry rot and cavity spot, respectively. Aluminum chloride (5mM) reduced dry rot by 25%, whereas aluminum lactate (5mM) decreased cavity spot lesions by 86%. These results indicate that various aluminum-containing salts may provide an alternative to the use of synthetic fungicides to control these pathogens (Kolaei *et al.*, 2013). Youssef *et al.* (2014) demonstrated that both sodium carbonate and bicarbonate exert a direct antifungal effect on *P. digitatum* and induce citrus fruit defence mechanisms to postharvest decay.

3. Plant growth regulators

Plant growth regulators are known to delay senescence and the onset of fruit rots. It is reported that indole acetic acid and maleic hydrazide were most effective against *Aspergillus* rot and *Rhizopus* rots of papaya fruits, while planofix (NAA, used at 0.01%) checked all rots except *Fusarium* rot in post inoculation treatment. Thakur *et al*. (1974) studied the effect of growth regulators (2,4-D, 2,4,5-T, NAA, ascorbic acid, and gibberellic acid) in the control of postharvest fungal diseases of apples, mangoes, pomegranates, bananas, potatoes, brinjals, and tomatoes caused by *Rhizopus* spp. and reported these to be effective in controlling rots. Similarly, Tak *et al*. (1985) reported that rovral (500 ppm), maleic hydrazide (100 ppm), and hydrogenated groundnut oil proved to be most effective both as pre- and post-inoculation treatment to control fruit rot of apples caused by *A. alternata*.

4. Biological control

To manage postharvest diseases of fruits and vegetables, there are a variety of possibly biological control techniques, including (i) constitutive or induced resistance, (ii) natural plant compounds, and (iii) antagonistic microbes. Here is a quick summary of these tactics:

4.1 Development and use of resistant varieties

Development and use of resistant varieties against pathogens is considered the most reliable method of disease management. However, it appears that a little attention has been paid to develop resistant varieties/hybrids against postharvest pathogens in horticultural crops. For developing resistant-type crops, certain desirable characteristics have to be incorporated into the susceptible varieties from the selected fruit and vegetable varieties, which are resistant to postharvest pathogens naturally (Wilson and Wisniewski, 1989). Generally speaking, we select cultivars with thin peels, low tannin contents, and high sugar contents, but sadly, all of these characteristics increase vulnerability to postharvest infections. A breeding programme should be created to solely use this sort of resistance because a plant breeder needs to understand that postharvest disease resistance is distinct from field resistance. The tetraploid potato (Solanum tuberosum) and the diploid wild species Solanum brevidens were utilised to create somatic hybrids. These hybrid tubers were tested for resistance to *Erwinia spbacterial* soft rot. *S. tuberosum*, which is now sexually transferrable, acquired the resistance. By developing an artificial inoculation assay, Bestfleisch *et al.* (2015) tested 107 genotypes of strawberry (*Fragaria* L.) genetic resources for resistance to *B. cinerea* under controlled circumstances. Five cultivars, including *Diana, Joerica, Kimberly, Fragaria virginiana* "Wildmare Creek," and *Fragaria vesca sub sp. Bracteata*, displayed somewhat resistance genotypes against the pathogen at 6 days after vaccination, with mean illness levels of 20%.

4.2 Natural plant products for biological control

Numerous antimicrobial constitutive and inducible chemicals found in fruits and vegetables have not yet been adequately investigated as biological control agents (Sharma and Pongener, 2010). These substances, however, can be added to other harvested goods or used in or on the plants where they are created. Natural additives, such as fruit seed extracts and essential oils, have shown to have effective antibacterial and antifungal properties and to be compatible with biopolymers, making them suitable for use in the creation of edible coatings (Kanmani and Rhim, 2014). Plant extracts are advantageous because they are inexpensive to produce, have minimal toxicity, and have strong biodegradability (Maswada and Abdallah, 2013). Additionally, most of the extracts are rich in polyphenols which can improve the antioxidant properties of the edible coatings (Silva Weiss *et al*., 2014). The use of edible coatings to preserve food product quality is a relatively low cost and environmentally friendly strategy with several advantages, including biodegradability, as well as the possibility to obtain a semipermeable barrier against gases and water vapor, thereby reducing microbial attack (Dhall, 2013). Furthermore, edible coatings can be combined with natural or synthetic active principles to prevent microbial decay in a more effective manner (Falguera *et al*., 2011). According to Dubey and Kishore (1988), numerous stored goods could be shielded from *Aspergilus flavus* and *Avicularia versicolor* biodegradation by using essential oils from the leaves of *Melanleuca leucadendron, Ociumanum,* and Citrus medica. These oils were functional at 500 to 2000 ppm concentrations. According to Wilson *et al.* (1987), ripening peaches release a variety of fruit volatiles, several of which are highly fungicidal. *Rhizopus nigricans*, *A. flavus*, and *P. expansum* were controlled from growing in wound-inoculated *Lingwu Long Jujube* and *Sand Sugar Orange* fruits when cinnamon oil at 2.0 percent (v/v) and 3.0 percent (v/v) concentrations was applied. The findings demonstrated that cinnamon oil has a promising future as a fruit application-specific natural antifungal agent (Xing *et al*., 2010). Papaya anthracnose caused by *C. gloeosporioides* was treated with lemongrass oil, and "Sekaki" papaya were subjected to lemongrass oil fumigation (0, 7, 14, 28 l/l) for 18 hours and at room temperature for 9 days. While papaya quality criteria were not significantly altered, lemongrass oil vapour at a concentration of 28 L/1 was most efficient against anthracnose of artificially inoculated papaya fruit (Ali *et al*., 2015). The effectiveness of methanol and chloroform extracts of eight *Cistaceae* species to control citrus sour rot decay, caused by *Geotrichum citri-aurantii,* was reported by Karim *et al*. (2016). Methanol extracts of these plant species exhibited more interesting activity against *G. citri-aurantii*, under both *in vitro* and *in vivo* conditions, compared with chloroform extracts. The disease severity was found to be as low as 5.19% and 6.04% when fruits were treated with the same methanol extracts. The methanol Cistus extract possessed sufficient antifungal activities which can be used in the citrus industry after it has been tested under production and natural infection conditions.

4.3 Use of microbial antagonists

Several microbial antagonists have been reported to control postharvest diseases of fruits and vegetables successfully. For their use, two basic approaches have to be Hybrid Membrane System Design and Operation 27 employed. The first approach is to promote and manage those antagonistic microbes that already exist on the fruits and vegetables themselves and the second approach should be to artificially induce the desirable microbial antagonists against postharvest pathogens. Both these approaches have been discussed in the following sections.

4.4 Natural antagonists

Naturally occurring antagonists are those, which are present naturally on fruits or vegetable peel, and are used to control postharvest diseases. Such antagonists have been isolated from fruit surfaces of apples and citrus and reapplied to the fruits as bio-control agents. Chalutz and Wilson (1990) found that when concentrated washings from the surface of citrus fruits were plated out on agar medium, only bacteria and yeast appeared. After dilution of these washings, rot fungus appeared on agar, indicating that yeast and bacteria may be suppressing their growth. It has been observed that when fruits and vegetables are washed, they are more susceptible to decay than those that are not washed at all.

4.4.1 Enhancing the bio-efficacy of microbial antagonists

During the past few decades, many attempts have been made to develop nonfungicidal methods to control postharvest decays in fruits and vegetables. These approaches include environmental modifications such as, storing commodities at temperatures suppressive to pathogen development, modified relative humidity and the atmosphere, and treatment with hot air or water (Smoot and Melvin, 1965; Fallik *et al.,* 1995) including resistance by applying elicitors or irradiation (Droby *et al.,* 1993a; Stevens *et al*., 1996), applying substances generally regarded as safe (GRAS) (Smilanick *et al*., 1999), applying wax formulation (De Lima *et al*., 2014), and sterilizing fruits and handling water with UV irradiation or ozone (Tukey, 1993). However, none of these methods, when used alone, provided satisfactory levels of decay control. Successful commercial control of postharvest diseases of fruits must be extremely efficient, unlike the control of tree-, field-, or soil borne diseases. Biocontrol agents cannot presently achieve such a level of control if used alone. However, for increased efficiency of bioagents, the following approaches have been suggested.

Addition of low level of fungicides:

Formulated biocontrol products like ASPIRE and BIOSAVE 110 provide cent percent control only when low doses of synthetic fungicides are also added to them (Droby *et al*., 1998). For example, citrus fruits treated with *Candida oleophila* and thiabendazol at 200mgmL/1 control decay effectively comparable to commercial fungicide treatment (Droby *et al.,* 1998).

Addition of nutrients and plant products:

The biocontrol activity of the microbial antagonists can be enhanced considerably by the addition of nitrogenous compounds (*L-aspargine* and *L proline*) (El-Ghaouth *et al*., 2000a, b) and 2-deoxy-D-glucose, a sugar analog. When applied in fruit wounds, the combination of *Candida saitoana* with a low dose of 0.2% (w/v) of 2-deoxy-D glucose control decay of apples, oranges, and lemons caused by *B. cinerea, P. expansum*, and *P. digitatum* (El-Ghaouth *et al*., 2000a, b). Liu *et al*. (2010a) treated grapes with TP and *Hanseniaspora uvarum* alone or in combination against *B. cinerea* and they reported that TP alone was effective in controlling gray mold in grapes at all concentrations. TP at 0.5% and 1.0% in combination with *H. uvarum* (1106 cfumL/1) showed a lower infection rate of gray mold. The addition of TP did not affect the growth of H. uvarum in vitro and significantly increased the population of *H. uvarum in vivo*. Another combination of TP and *Candida ernobii* was found to be effective against postharvest disease (*Diplodia natalensis*) in citrus fruits (Liu *et al.*, 2010a).

The addition of TP did not affect the growth of *C. ernobii in vitro* and significantly increased the population of *C. ernobii in vivo*. It was direct because of the inhibitory effects of TP on spore germination and mycelial growth of *D. natalensis* and indirect because of the increased populations of *C. ernobii in vivo*. The control was better when either *C. saitoana* or 2-deoxy-D glucose was used. The curative activity of the combination of *C. saitoana* with 2-deoxy-D-glucose represents 34 Postharvest Disinfection of Fruits and Vegetables a substantial improvement over existing microbial biocontrol product. The treatment of peach fruits with *C. laurentii* at 1108 cfumL/1 alone or in combination with methyl jasmonate at 200µmol L/1 inhibited the lesion diameter of brown rot and blue mold rot caused by *M. fructicola* and *P. expansum* (Yao and Tian, 2005). The most efficient treatments using *Meyerozyma guilliermondii* (strain 443) were those with 2% gelatin or 2% liquid carnauba wax, both of which reduced anthracnose by 50% in postharvest papayas. Electron micrographs of the surface tissues of the treated fruits showed that all application vehicles provided excellent adhesion of the yeast to the surface. Formulations based on starch (2%), gelatin (2%), and carnauba wax (2%) were the most efficient at controlling fungal diseases in postharvest papayas (De Lima *et al.*, 2014).

Future line of work:

The management of postharvest diseases is a difficult task and it could be intensively focused on by scientists, administrators, and policy makers. Future investigations should be focused on the following areas.

(i) Proper diagnosis of postharvest diseases by using modern biotechnological tools.
(ii) Precise estimation of economic losses caused by each major fruit rot.
(iii) Forecasting of postharvest diseases with suitable means.
(iv) Exploring the possibility of use of nonpathogenic or attenuated strains of pathogens.
(v) Identifying compounds, which when injected into the trunk or sprayed on foliage long before harvest, are translocated to the fruit, making it resistant to infection by postharvest pathogens.
(vi) Determining the nature of constitutive and induced resistance in the harvested fruits.
(vii) Improving the efficacy of physical, chemical, biological, and cultural methods, and integration of different methods of disease management.
(viii) Using biotechnological tools for producing resistant fruits with good-quality characteristics.
(ix) Strategies for enhancing wound defense mechanism in harvested fruits.
(x) Identification of genes that promote epiphytic antagonists.

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DROUGHT PRONE TECHNIQUES: AN IMPORTANT TOOL FOR SUSTAINABLE AGRICULTURE IN INDIA WITH SPECIAL REFERENCE TO DRY FARMING

Divya Nigam

Department of Economics,

Lala Lajpatrai College of Commerce and Economics, Mahalaxmi, Mumbai-34

Corresponding author E-mail: nigamdivya99@gmail.com

Abstract:

India being primarily the agrarian based economy, half of our population depend on agriculture for their livelihood .Agriculture is not only the provider of food but supplies raw materials to industries. However even two decades past twenty first century, Indian agriculture still dependent on weather conditions for good crop. Around 55% of India cultivable land depends on precipitation, amount of rainfall during current monsoon season .If monsoons are not favourable, entire agricultural and related industries are adversely affected. It is found that over the years the spells of drought and severe water shortages have affected more than 300 million people in the country not just in terms of food shortages but also livelihoods, of both agriculture and industry. It is the need of the hour to fix this problem and make efforts to switch over to effective methods of water management.

If India has to achieve sustainable development in agriculture, the challenging task for the farmer, managers, engineers and researchers is to develop and practise such suitable techniques which favour sustainable use of water in agriculture, increasing the productivity with minimum usage of water.

The article attempts to examine in detail various appropriate techniques which are now being practised in drought prone areas of the country and measures taken by the government to achieve sustainable agriculture production and development.

Keywords: Precipitation, Hydrological drought, sustainable production, water conservation, rain fed, water scarcity.

Objectives of the study:

a. The study aims at delving in detail why drought prone and water saving techniques are needed in India’s agriculture.
b. The study focuses on application of various water saving methods of irrigation with special reference on dry farming along with effective water management measures which are being taken by the government currently.
c. Towards the end paper aims to draw inferences as to what extent these drought prone techniques have contributed towards agriculture development on a sustainable basis.

Research methodology and period of study

The study is based on secondary data collected from various sources like internet websites, newspaper clippings, journals, various research reports on dry farming techniques etc.

Overview:

During last few years various parts of the country have suffered acute drought like situation, namely, parts of Andhra, central part of Madhya Pradesh, Rajasthan, etc. Ministry of water resources defines metrological drought, hydrological drought and agricultural droughts. In this agricultural drought needs to be addressed which is identified by four consecutive weeks of metrological drought when weekly rainfall is 50 mm or less from mid May to mid October.

To tackle India's water crisis a large scale national water infrastructure development programme is needed under which a comprehensive network of big water reservoirs as well as regional and local water storage system should be laid out. Along with this advanced agricultural irrigation system needs to be introduced, especially in low rainfall areas of India, utilizing advanced technology which is used in arid regions of the countries such as U.S, Australia and Israel. Modernisation of urban water works too is being emphasized in order to prevent large scale loss of water through leaking and damaged pipes which would reduce the wastage and increase water availability for productive activities.

While there is a need for adopting holistic approach in mitigating and managing the drought, a sustainable solution would primarily consist of large scale adoption of modern and suitable techniques of agriculture which require less water.

Techniques of agriculture for less rainfall regions being used in the last few years

Deficit irrigation and irrigation management.

This method is used in applying water below full crop water requirement or Evapotranspiration (ET).Research has established that there is potential for improving water productivity in many crops. India has successfully adopted regulated deficit irrigation (RDI) successfully in fruit trees resulting in improving water productivity and enhancing farmers' profits.

Deficit irrigation and water productivity

Since last few years enhancing the importance of deficit irrigation concept is being used which is defined as yield or net income per unit of water used. Many reasons for the increase in WP under deficit irrigation. The irrigation increases crop evapotranspiration linearly up to point where relationship becomes curvilinear because part of water applied is lost. The yield reaches maximum value at this point and additional quantity of water doesn't increase the yield any further. But it's difficult to accurately identify that maximum yield point and hence when water is not scarce, irrigation is applied in excess to avoid risk of low productivity.

Rain fed agriculture and water management

Like most of developing nations rain fed agriculture has emerged as one of the most common and effective method of cultivation. Rain fed agriculture accounts for about 57% of country's net sown area, contributing nearly 40% of the total food production and 60% of the value of agriculture GDP of India. These areas assume special significance in terms of ecology, agricultural productivity and livelihood of millions. 61%of Indian farmers rely on rain fed agriculture. But since most the farmers in India are small and marginal ones, they do not practise much intensive cultivation. Farmers in rain fed areas earn hardly 20-30% from farm related activities. Rain fed area account for 89% production of millets, 88% pulses, 73% cotton, 69% oilseeds and 40% of rice production in the country. Hence to help such farmers to increase use of available dry land, modern technologies and new measures have been initiated by Govt. For rain fed crops, water shed development is being prioritised in the recent years to increase the yields. Techniques like use of supplemental irrigation, rain catchment systems, sand dams called bandaras is being used in various parts of Maharashtra. These techniques have facilitated water availability to rain inconsistent regions of the country.

Dry farming

Dry farming is an improved system of cultivation focussing on soil and water management designed to conserve maximum quantity of water on particular piece of land. It involves cash cropping eg, Jatropha cultivation can reduce magnitude of petroleum crisis since liquid produced by it can be added to petroleum products without reducing the efficiency. Also dry land agriculture has the potential to produce fodder and cattle feed. Thus it has played crucial role in white revolution in India. Of the 141 million hectares of estimated crop area in the country, nearly 80 million hectare is under dry land farming which constitutes 52% of total cultivable land and contributes to more than 44% of the food basket. In our country more than 75% of farmers engaged in dry farming are small and marginal. In this light government has taken many initiatives to improve dry farming technologies to increase the yield and raise the economic status of the farmers in consonance with poverty alleviation programmes.

Characteristic Regions of Dry land Agriculture

	Region	**Crops Grown**
1	Eastern India	Ragi, Jowar, Bajara
2	S.W. Uttar Pradesh	Bajara
3	Vindhya Region	Jowar,Maize, Pulses
4	Narmada-Tapi basin	Jowar, Wheat
5	Deccan plateau uplands	Cotton, Jowar
6	Telangana	Jowar
7	Non- irrigated areas of Rayalseema	Ragi, Groundnut
8	Plateau region of Karnataka and TN uplands	Jowar, cotton

Challenges of Dry land farming in India which still persist:

a. Since dry land farming involves planting of crops in a scattered way, and in fewer numbers overall than in wet farming, weeds are destroyed so that redundant plants do not compete with the plants for water. This is called Strip cropping which entails lots of effort and time to ensure that the soil is not deprived of moisture.

b. Management of soil conservation and water resources
c. Need to evolve high yielding crop and drought resistant crop varieties
d. Low cost agricultural inputs which are locally suited
e. Adequate and timely availability of credit to purchase inputs
f. Moisture stress, selection of limited crops, disposal of dry farming products, quality of produce are some issues of dry land farming in India in the recent years.

Initiatives taken in the recent years to improve efficiency and productivity of Dry land agriculture

A. Water harvesting:

It is the process of capturing rain where it falls and taking measures to keep that water clean. Methods include capturing run off from rooftops, capturing runoff from local catchment areas, and capturing seasonal floodwaters from local streams.

B. Agronomical practises on scientific basis:

These include crop rotation, intercropping etc.

C. Soil preparation:

It is necessary to prepare the soil before sowing as soil usually loses its fertility due to continuous farming**.** Hence for its replenishment steps like ploughing the field, levelling and manuring are undertaken before sowing.

D. Organic farming:

In the last few years, the concept of organic farming has gained tremendous popularity as the crops grown under this system are considered to be having very high degree of nutrients. In this use of synthetic inputs like pesticides, fertilizers, hormones etc. is avoided and natural techniques of cultivation like crop rotation, organic wastes, farm manure etc. are used.

E. Watershed management:

This is the process for effective soil and water conservation with minimum pollutant losses. Methods being used are vegetative barriers, contour bunds building, furrow ridge method of cultivation across slope, irrigation water management through drip sprinkler and sprinkler methods and planting of horticultural contour species on bunds.

F. Ecological conservation techniques:

These methods include prevention of soil erosion, water infiltration, and retention, carbon sequestration in form of humus.

G. Use of HYV varieties of crops (drought resistance crops)

Dry farming techniques in India are adopted to cover rain fed agricultural activities dominated by low water needing crops in the arid and semi-arid regions like states of Madhya Pradesh, Chhattisgarh, Uttar Pradesh, and Tamilnadu, Central Rajasthan, Saurashtra region of Gujarat and rain shadow region of Western Ghats. With the rising population, the gap between demand and supply is widening .Around 50% of cropped area is under rain fed farming system. Such expansive lands consume 25% of total fertilizer consumption of the country .Crop productivity has been very low due to poor level of management. An integrated approach has been proposed by the Govt. for the development of dry land farming and financial institutions like NABARD and cooperative banks have now actively involved themselves in extending financial help for running viable dry land farming projects in the country.

Progress of Dry farming in the recent years

During the last few years dry land farmed crops like winter wheat, corn, beans, sunflowers, water melons, millets etc. have increased. In some parts of the country advanced farming technology to enhance production in dry land areas has been introduced. The survey conducted inferred that only 10 states have more than 50% drought resilient area. Tamilnadu was at the top with 56.7%, followed by Andhra Pradesh with 53.4%, Telangana with 48.6%, Karnataka with 17.3% and Kerala 19.1%.Now the initiatives have been proposed to be taken to improve productivity of dry land farmed cops through application of advanced technologies like sub surface drip irrigation, and cultivation of drought resistant varieties .Crops like maize which need just 2.5 lakh litres per hectare water can be grown in arid regions.

In various districts of Punjab, like Baghpat, where groundwater is very low, some pockets are now cultivating mustard, barley with the application of advanced technologies.

Organic farming is being promoted under the schemes like Paramparagat Krishi Vikas Yojana PKVY and Mission Organic Value Chain Development for North Eastern Region.

Recommendations:

Policies and practises of irrigation water management will have to emphasize on specific objectives according to the causes of water scarcity. Certain priority issues which require immediate attention are evaluation of potential of irrigation as a means for environmentally sustainable land use and food production, developing appropriate tools for assessing and controlling the impact of low quality water in irrigation, improving land evaluation criteria and methods of irrigation planning to assess impacts on environment and developing low cost nature friendly techniques for waste water reuse systems.

Another area which should be taken care of is water quality management which includes water quality monitoring and development of low cost techniques of assessment, effective disposal and reuse of drainage water, salts, and agricultural wastes in arid and semi-arid lands and effective management system to minimize water quality degradation.

For sustainable efforts reuse of waste water and conversion of saline water into usable are very important. Despite several efforts by many global and national agencies, the safe use of those waters at affordable cost still remains elusive.

Further more innovative issues for institutional building, which mainly concern human resource development, have to be considered since the application of new technologies and improved management cannot be successful unless the knowledge base of all the stakeholders is updated.

Conclusions:

Hence in the light of current situation, it would be in fitness of things that issues related to manmade desertification leading to aggravating water shortages are dealt with ruthlessly and stringent regulations should be made and enforced effectively to curb this alarming and dangerous trend. Population is growing and the demand for water faces an increased competition among water user sectors and regions. However, rainfall is not adequate in many regions which restricts the quantity of water resources available. A bigger worry is deteriorating quality of water making water resources unfit for intended use. There is a need to find new approaches in agriculture to cope up with water scarcity alongside adopting sustainable water use issues. The sustainable use of water resource conservation, environmental friendliness, appropriateness of technologies, economic viability and social acceptability of development issues has to be the priority for agriculture in water scarce regions.

Nevertheless despite various alternative techniques traditional irrigation is being continued and area under irrigation has also expanded. It is therefore desirable that efficiency of use of irrigation water is enhanced. Farming system research to develop location specific technologies is now being intensified in rain fed areas. Also a comprehensive strategy is needed to convert grey areas into green areas to make a second green revolution possible which would involve three pronged strategy of water shed management, hybrid technology and small farm mechanisation.

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PRECISION FARMING: AN APPROACH TOWARDS SUSTAINABILITY AND ADVANCEMENT IN AGRICULTURE

Kavita*, Preetam Kumar and Shweta

Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar

***Corresponding author E-mail:** kavita.yadav@hau.ac.in

Abstract:

Injudicious and unhealthier use of farm input like blanket application of agrochemicals is adding to the problems of environment concerns as well as it is not economical for farmers. It necessitates the shifting of our focus from high input based agriculture to low input one, which is sustainable also. Moreover, increasing interests towards automated data acquisition and information processing is building a platform for application of technology driven precision agriculture in India. Benefits occurring from precision farming are quite phenomenal if the technology is well managed on the farm entrenched to the condition and demand of the farm. Precision farming includes utilization of many practices such as remote sensing, global positioning system (GPS), yield monitoring, yield mapping, variable rate applicator (VRA), geographical information system (GIS), crop modelling and site specific management zones (SSMZ). Site specific application of production inputs not only cutoff extra costs, but also increases resource use efficiency with additional benefits of ecological balance and environment conservation.

Keywords: GPS, GIS, SSMZ, site specific application

Introduction:

The world is approaching towards the third farming revolution with a motive of further increasing agricultural productivity as well as sustainably managing all the resources. The first farming revolution started in 1900's which led to the foundation of mechanized agriculture making farmers capable of producing food enough for 26 people. Long after it the second farming revolution i.e, green revolution attracted the attention of farmers and scientists all over the world. Introduction of high yielding cultivars combined with use of agrochemicals (fertilizers, herbicides and pesticides) and adoption of land reforms made India self sufficient in terms of food security. But, as we know, everything has its Pros and Cons, Green revolution also left some limitations with us such as declined forest cover, soil degradation, resistant in plant to herbicides, pest resurgence, ground water depletion, outbreak of diseases and other human disorders. After green revolution, India entered a stagnation phase with reference to agricultural production where no further addition of inputs like agrochemicals can increase the production from exploited soils. The ongoing situation with additional duress emanating from population surges and climate change scenario is persuading Indian agriculture towards a third modern farming revolution and precision farming is an important part of it. Precision farming can be described as analogous to a pill taken to target an ailment as it works on a specific site for specific crop and land suggesting a specific management practice. Soil of a single field on earth is not homogeneous, it varies considerably creating heterogeneity in field. When the soil is not even homogeneous throughout the field, how can one consider that a single practice or the same doses of nutrients and other agrochemicals will be beneficial all over the field. It might create nutrient deficiency at some spot and nutrient excess at some spot. Similarly, the drainage coefficient and slope level also differs from spot to spot in a field. That's why we need to take a step towards site specific management for all the agricultural practices which is the pivotal idea behind adoption of precision farming.

Concept of Precision farming

Precision farming is an idea of managing the agriculture by making use of inter and intra field variability in fields after observing and measuring them and accordingly responding in a well managed way. Precision farming uses system and holistic approach for the present agricultural issues of balancing productivity with environmental concerns employing implementation of advanced information technologies like GPS, GIS and provides a new solution. It includes description and modelling of variation in plant species and soils emphasizing integrated agricultural practices to attain the site-specific requirement, increase economic returns and reduced energy input with lesser impact of agriculture on environment. Precision agriculture is also called site specific crop management due to its spatial variability based crop management feature. USDA elucidated it as "Precision agriculture, or site-specific crop management (SSM), uses a variety of technologies such as sensing, information technologies, and mechanical systems to manage different parts of a field separately". Concept of precision farming using technology is new but the precise management in a field can find its roots from the ancient agriculture. But the faulty agricultural practices since the green revolution like adoption of generalized regional recommendation in every field are in continuous use till now. Also, the recommendation to farmers were given on per hectare basis such as for control of any insect or disease without knowing the extent of the damage caused and the percentage of area affected. In this sense, precision farming can be defined as sub-field crop management similar to traditional agricultural practices in which small scale non-mechanized farming enables application of spatially variable treatments in a single plot. It is the management strategy which employs detailed site specific information to precisely regulate the use of production inputs. The close monitoring of land's characteristics and remote management of farming practices in-dispenses the use of smart technologies involving data collection from satellites and drones. Precision farming is implementation of data sensors in field, in soils and on animals for real time data transmission allowing cost effective and accurate means to predict as well as protect the growth of agricultural crops.

Adoption of precision farming prerequisites the information on spatial variability in crop conditions and soil fertility status. Space technology which involves GPS (global positioning system) and GIS (global information system) accomplishes the need of deriving information about variable soil and plant attributes (soil moisture, crop phonology, evapotranspiration, nutrient deficiency, insect, disease and weed infestation); helping in optimizing inputs, maximizing yield and income from a crop. Precision farming holds a good promise for small farmers in developing countries as most of the agricultural inputs were not used efficiently in the field. The substantial yield improvement with relatively less use of external inputs enabling reduction in cost of production might improve their living status alongside protection of environment from excess and unhealthier use of inputs. Precision farming assists a farmer in improving his field or farm owing to agronomical, technical, environmental and economical perspective. Agronomical perspective involves adjustment of cultural practices considering the real demands and requirements of crop like better fertilization and water management. In technical perspective, paramount importance is given to the time management which assists in planning and execution of agricultural activities at the best time. Reduction of agricultural impacts by reducing the wastage of energy and resources while protecting the surrounding is a view of environmental perspective of precision farming. And, economical perspective includes the increment in benefit cost ratio of a commodity and increased efficiency of resources attained by the holistic management of farm in every perspective. Accomplishment of a single perspective in precision farming can never result in the best output making the application of system and holistic approach essential.

Principle of Precision farming

Precision farming lies on the foundation of managing a farm in correct manner according to exigency of the crop and soil. The 5 R's discussed under appropriately describe the nature and extent of precision farming.

- ✓ **Right input:** Selection of the input which is required by the crop and soil is utmost important. Without sorting the right input, it is not possible to follow the other R's and it alone leads us the half way. As we know, spatial variability exists in a field and the whole field thus doesn't require the same input. The right input vary from spot to spot in same field.
- ✓ **Right amount:** After identification of the input which soil or crop in a farm requires, check out the amount of input required. For example, if a crop requires nitrogen, it is crucial to

know how much amount of nitrogen is required by the plant. It can be done by soil and plant analysis using laboratory methods which, however is not possible for a farmer, they can take advantage of remote sensing imagery which make use of absorbance, reflectance and transmittance of radiations in different range like red, infrared to calculate indexes for identification of stress type and its extent.

- ✓ **Right place:** Application of an input at a right place definitely makes a difference compared to its application at some other place. In horticultural crops, it is often suggested to apply the fertilizer a certain distance away from the crown in soil due to the fact that plant roots (site of uptake of moisture and nutrients) are not present near the crown, they are widely spread away from stem in search of moisture and nutrients.
- ✓ **Right time:** An input or a practice should be used when it results in maximum benefit until and unless the crop or soil suffers a loss. Plants should be irrigated in the early morning or evening and not in the afternoon due to increased evapo-transpiration and to preserve the precious resource.
- ✓ **Right manner:** The best and correct way of applying an input should be first known to avoid any loss to crop and wastage. For example, if crop requires nitrogen or potassium in the late stage of its growth cycle, foliar application of the nutrient is beneficial as it will be assimilated in the plant sap very fast compared to the uptake from soil.

Need of Precision farming in India

India is a developing country producing enough for its population and also exports food grains, fruits and vegetables to foreign countries. This self sufficiency came from the green revolution but still the highest yield of many major crops on a farm is much lesser than the average production of crop in other high productive countries. India has not even achieved the maximum potential yield of high yielding varieties which might be ascribed to the non-judicious use of inputs and lack of technology in deciding and allocating the best practice use among different fields and in the same field in accordance of spatial variability. Undoubtedly, green revolution played a major role in development of India in terms of food security but it also had many limitations such as loss of soil fertility, depletion of underground water resources and their pollution, soil toxicity and erosion, higher incidence of diseases in human and livestock, resistance in weeds, pest resurgence and global warming. Green revolution ensured the depletion of natural resources, the extent of which is supplemented by the one per cent annual population growth rate of India. In the light of the above points, two major areas necessitating the adoption of precision farming in India are

- ❖ To overcome the fatigue of green revolution
- ❖ To reduce natural resource depletion

Tools and components of Precision Farming

Precision farming basically relies on the interaction among three broad and cardinal components which are information or database, technology and management. Further details of these components are described as under:

1. **Database:** Crops and soils both vary spatially and temporally under field conditions. Detailed information on soil, crop and climate properties is necessary to develop database for realization of the full potential of precision farming. The entire crop yield monitoring is of paramount importance and acts like a starting point for precision farming as it gives farmers to look upon their practices and a desire to rectify them. Second database results from the detailed analysis of soil through regular sampling. Precision farming involves the decision making process about the sampling process with regards to number and timing of samples and what properties to be studied. Database is prepared using the following properties (Mandal and Maity, 2013; Ge *et al*., 2011) :

Table 1: Various sampling elements used in database formation

Sr. No.	Sampling element	Properties of sampling element
1.	Soil	Physical condition of soil, Soil texture, Soil structure, Soil moisture, Organic and inorganic carbon content, Macro and micro nutrients, Cation exchange capacity (CEC), electrical conductivity (EC) and pH
2.	Crop	Crop type, Plant population, Crop stress (extent and potent areas), Nutrient content in leaves (deficit or excess), Weed patches (Type and intensity), Insect and disease infestation (species and intensity), Crop yield, Harvest swath width
3.	Climate	Temperature, Humidity, Rainfall, Solar radiation, Wind velocity, In-fields variability (Spatially or temporally)

2. **Technology:** Success in adoption of precision farming is achieved with the help of recent advances in information technology and space technologies which provided new tools for assessing soil and crop related variables and monitoring yields. The component technology of precision farming system involves a number of sub components which came into action one after another fulfilling the objective of the study. While analyzing soil and plant characteristics, GPS (Global Positioning System) is used for identification of location from where the data is recorded. Next sub-component after collection of data which helps in organisation of data into usable forms like different layers of field maps (raster and vector data form) is GIS (Geographical Information System). Remote sensing allows identification

of stress, pest and disease incidence in plants and variables in soil. Precision farming doesn't ends here, it also includes the application of variable rate of inputs in real-time based on the requirements using variable rate technology (VRT). The various sub components of technology including a vast array of hardware, software and equipments are discussed hereby:

a) **Global Positioning System (GPS):** GPS is defined as navigation system based on the network of satellites which helps user in recording positional information with accuracy of 100 to 0.01m (Lang, 1992). GPS works as an automatic controlling system with the help of antenna, receiver and DGPS (Differential Global Positioning System- the light or sound guiding panel). Signals broadcasted by GPS satellites are used by GPS receivers to calculate their position. GPS system allows farmers to reliably find the accurate locations where they need to apply the right amount of right nutrient in the right manner. GPS provides instantaneous and continuous information of position, in real time, while in motion. GPS receivers either carried to the field or are mounted on the instruments which provides precise location information and DGPS is a technique of improving GPS accuracy by using pseudo range errors at a known location to improve measurements made by other receivers. DGPS is necessary for accurate measurements which are required for comparing location of soil sample and their analysis to soil maps, fertilizer and pesticide recommendations to fit soil properties and conditions like clay content, organic matter content, relief and drainage. Also, DGPS aids in monitoring and recording yield data as well as making tillage adjustments (both vary across the field).

b) **Geographical Information System (GIS):** GIS allows presentation of spatial data in the form of maps and is used in agriculture to store, retrieve, analyze data and maps. GIS helps producer in comparing various types of agricultural data, finding relationship between and within different types of datasets and visualizing, interpreting and presenting the analyzed results in form of maps and charts. Digital maps thus formed includes information and features interrelated with time and coordinates. GIS data can also be used to evaluate current and alternative management practices by combining and manipulating data layers.

c) **Sensor technologies- Remote sensing:** Sensor based technologies are used to measure humidity, temperature, vegetation type, texture, structure, nutrient level etc. One such technology is remote sensing which collects the information about an object or character on soil surface without coming directly in the contact with earth surface by using sensors present on satellites. Data collected in the form of images with the help of these sensors have capabilities for manipulation, analysis and visualization. Incorporation of remote sensing imagery with GIS allows gathering of data even from remote areas and collects data from a very wide area in small time.

d) **Grid soil sampling and variable rate technology:** Grid soil sampling uses the same principles as normal soil sampling does, the only difference is the intensity of sampling which is higher in grid soil sampling. In systematic grid sampling, soil samples also have the location information allowing data mapping. An application map is prepared using all the samples from grid soil sampling and loaded in the computer connected with variable rate applicator. Variable rate applicator involves the use of automatically managed variable rate technologies (VRT) which set the delivery rate of farm inputs in accordance of soil types noted in a soil map.

Computer connected with variable rate applicator uses the application map and GPS receiver directs product delivery controller which changes the kind and amount of an input based on the application map prepared using grid soil sampling data.

3. **Management:** The next key area in precision farming is to combine the data generated with the existing technology is to result in a comprehensive and operational system. A farmer should adopt new levels of efficient management on the farm.

Methods of Precision farming

Precision farming involves application of two types of methodologies *i.e.*, map based and sensor based. Each methodology has their own goodness and benefits and also, both can be used together in a complementary manner. Map based methodology uses grid sampling in a field whereas sensor based methodology utilizes real time sensor and feedback control. Table 2 given below displays the differences in both the methods and their comparative advantage.

Table 2: Comparison of map based and sensor based methods of precision farming

Sr. No.	Map based	Sensor based
1.	Use of grid sampling, lab analysis and site specific maps	Use of real time sensors
2.	Application of GPS/DGPS compulsory	Not necessarily required
3.	More time consumption	Less time required
4.	High cost of soil testing and analysis are some limitations	Lack of sufficient sensors for recording information about plant and soil
5.	Sampling units are generally 2 to 3 acres	Easy detection of individual spot
6.	Highly adopted in developing countries	More adoption in developed countries
7.	Operations are quite difficult and require skills	Operations are comparatively easy with technological skill requirement

Steps in Precision Farming

1. Characterization and interpretation: Identification and assessment of variability in soil, yield and in season crop conditions using grid soil sampling, yield maps and crop scouting, respectively. Crop scouting results in later stages can also be used to explain the reason of yield variability in field.
2. Management and monitoring: Field variability should be managed after yield monitoring, mapping and quantification using variable rate application and make farm flexible to adapt to new cultural and technological changes based on continuous monitoring of outcomes.

Conventional practice v/s Precision farming

Farming practices adopted during green revolution are still in operation and followed by farmers without knowing their shortcoming. Apart from being convenient and handy, conventional practice reduces resource use efficiency and increases their wastage, these limitations now need to be pulled out of the use and replaced with the modern technology applications. Comparison between precision and traditional conventional farming discussed hereby showcases the benefits of precision farming over conventional farming. Demand and field variability based fertilizer application in precision farming at variable rates compared to blanket application followed in conventional farming allows the high fertilizer use efficiency limiting nutrient fixation and run-off, thus preventing pollution of streams, rivers and soils. Early detection of plant stress caused by biotic and abiotic factors permits their control before crop suffers severe damage improving yield and productivity. Precision farming increases water use efficiency with modern technology application derived from real time plant water status and soil moisture data obtained with remote sensing compared to injudicious water use based on presumptions of farmers emanating from the recommended number of irrigation and critical stages suggested in package of practice of a crop. Precision farming ensures rectification of degraded soil, enhanced quality of produce with reduced cost of cultivation changing the socioeconomic status of farmers encouraging favourable attitude development towards modern technology adoption. Also, precision farming holds utmost significance in climate smart agriculture. The key benefit of Precision farming includes:

1. Decision accuracy
2. Advancement in agriculture
3. Software based suitable planning
4. Weather prediction
5. Easy marketing of good quality produce with technology advancement

Economic feasibility of Precision farming in Indian agriculture

Technological application in Indian agriculture are presently at infant stage and the high prices of equipment and services are hard to pin down affecting the adoption of precision farming at ground level. Most of the farmers are under delusion that without these most advanced and costly equipments, precision farming is not possible. Study conducted by Shruthi *et al.* (2017) and Shruthi *et al.* (2018) in paddy fields showed positive NPV (Net Present Value) and high benefit cost ratio without the use of high cost equipments like yield monitors. Farmers can start precision farming on their farm with low cost technologies and management practices like levelling, grid making, soil analysis etc. Equipments are not affordable in Indian farming on individual basis, but on cooperative and collaborative basis, farmers can easily adopt precision farming. Precision farming cut-off the extra cost incurred due to blanket application of fertilizers, pesticides which indirectly helps in reducing the weed density and growth improving crop yield and reduces herbicide need and labour costs for their management. In similar way, laser land levelling reduces extra cost incurred on tillage practices to manage water flow in the field to avoid situation of waterlogging and allowing easy drainage with approximately increasing cultivated land area by 3-5 percent and water application efficiency. Improved soil moisture distribution, water saving and water use efficiency with reduced depth of applied water and time consumed for irrigation were observed with laser land leveller compared to conventional in sorghum field at Navsari, India with increased grain yield (Kumari *et al.*, 2022). High benefit cost ratio, yield and water use efficiency achieved with laser levelling in rice and wheat compared to unlevelled field and traditional levelling showcases the benefits a farmer can have after the application of precision farming (Naresh *et al.*, 2014). Application of precision farming on farm thus increases productivity per rupee spent making its adoption economically viable.

Constraints in adoption of Precision farming in India

1. Culture and perception of farmers- lack of awareness, rigidity to change, influence of people
2. Land fragmentation i.e., small land holding of a farmer
3. Quality and high cost of equipments
4. Knowledge and technical gaps
5. Less exposure of farmers to success stories
6. Complexity in technology usage- availability and accessibility
7. Heterogeneity of cropping system and market imperfections
8. Lack of information about government initiatives like subsidies

Successful examples of Precision farming in India

❖ Tata Kisan Kendra (TKK): TKK was a Tata Group initiative under the aegis of Tata Chemicals (TCL) using technological advances to solve India's social and economic problems. The Kendras give farmers information about crop health, pest attack and covers various crops predicting their final output. Also, they help farmers with finance by providing credit, insuring their crops against natural disasters (Agropedia, 2012).

- Tamilnadu Precision Farming Project: The project TNPFP was first implemented in 2004-05 at Dharmapuri and Krishnagiri districts in Tamilnadu, which suffered from water scarcity and traditional farming practices were followed by farmers. The 400 hectare area was covered under project with main focus area to increase yield by 40-60 percent and effective market linkage. Key technology used were Remote sensing, Chisel plough, Hi-tech community nursery, drip and fertigation system, growing crops and growing with crops, market support with benefits like 30 percent premium price in market, less labour dependence and 30-40 percent more water economy (Anonymous, 2022).
- Precision Agriculture Development (PAD): PAD is a non-profit organization with a mission to help and support small farmers in developing countries by giving customized information and services to them for increasing productivity, profitability and environmental sustainability. The programme started as a small pilot project in Gujarat for serving about 10000 farmers on cotton crop. Developed in six states at present to encompass five initiatives on 24 crops and litany of pests and diseases. Initiatives started by PAD are Ama Krushi in collaboration with the Department of Agriculture and Farmer's Empowerment, Govt. of Odisha (2018), Coffee Krishi Taranga in Karnataka, Kerala and Tamil Nadu in collaboration with the Coffee Board of India (July 2018), Krishi Katha in collaboration with the West Bengal Accelerated Development of Minor Irrigation Project (July *2019),* Project HARIT (Harnessing the power of Agricultural Residues through Innovative Technologies) in Punjab and Haryana (2018) in collaboration with The Nature Conservancy (TNC), the International Maize and Wheat Improvement Center (CIMMYT) and the Borlaug Institute of South Asia (BISA); and Krishi Tarang in Gujarat.

Policy approach to promote precision farming at farm level

1. Identification of niche areas for promoting crop specific precision farming
2. To study the overall scope of precision agriculture, multidisciplinary teams should be created
3. Complete backup support to farmers must be provided to develop models which can be later replicated on a large scale
4. Pilot study on farmers field should be conducted to check out the result of precision agriculture implementation
5. Awareness creation among farmers about the consequences of usage of imbalanced doses of farm inputs

Future prospects and scope for precision farming in India

Precision farming is a proven technology but its adoption is still limited to developed countries. Major problem encountered in India is small farm holding size as more than 57.8 percent of operational holdings are lesser than one hectare. In north-western states, which are highly productive and vast areas under the same crop suggesting the consideration of contiguous fields as a single field for implementation of precision farming for major food grain crops and high value horticultural crops. All the farms are not suitable for adopting all the elements of precision farming, it varies from field to field creating an opportunity for Indian farmers to adopt precision farming based on their requirement. Government is providing subsidies and also intimating the benefits of precision farming to every corner of the country; and the effective coordination among public and private sector is strengthening the adoption and implementation of precision farming to achieve fruitful success. Precision farming in near future is seen as an important factor to transform the green revolution in evergreen revolution. Precision farming is also important for increasing economic returns and reducing the energy input thus, helping the environment to sustain its health.

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FORECASTING OF AREA, YIELD ANḌ PRODUCTION OF NIGER IN OḌISHA

Gourav Sahu, Abhiram Dash, Akhilesh Kumar Gupta and Manoranjan Sen

Department of Agricultural Statistics,

College of Agriculture, OUAT, Bhubaneswar

*Corresponding author E-mail: abhidash2stat@gmail.com

Abstract:

The state of Odisha is one of the highest producer of Niger seeds in India. Niger (*Guizotia Abyssinica*) is mainly grown as kharif crops, whereas in Odisha, it is grown as Rabi crop. Varieties like GA-10, Utkal Niger-150 are generally grown in the state. It has yield potential of 800-1000kg/ha under optimum growing conditions. Forecasting of Niger production is of utmost importance for the agri-planners for making policies regarding package of practices of the nige rcrop. The present research is carried out on forecasting area, yield and production of Niger in Odisha by using ARIMA model.

ARIMA, the most widely used model for forecasting is used in the study. The data on area, yield and production of Niger are collected from 1970-71 to 2019-20 are used to fit the models found suitable from ACF and PACF plots. The ACF and PACF plots are obtained from stationarized data. The best fit model is selected on basis of significance of estimated coefficients, model diagnostic tests and model fit statistics. The selected best fit model is cross validated by refitting the model by leaving last 5 years, 4years, up to last 1 year data and obtaining one step ahead forecast for the years 2015-16 to 2019-20. After successful cross validation the selected best fit model is used for forecasting the area, yield and production of Niger in Odisha for the future years 2020-21, 2021-22, 2022-23.

The ARIMA model found to be best fit for area, yield and production of Niger are ARIMA(0,2,2), ARIMA(1,1,0), ARIMA(1,1,0) respectively. All these selected models are fitted without constant as the constant term is insignificant for all these cases. The forecasted values for area under Niger is found to increase in the future years which is responsible for increase in forecasted values of future production despite the yield remaining stagnant for future years.

Key words: ARIMA, cross validation, forecast, model diagnostics, model fit statistics,

Introduction:

Oilseeds occupy an important position in the agrarian economy of India. Oilseeds constitute a very important group of commercial crops in India. In India, Niger is grown on an area of 2.61 lakh ha mainly during kharif. However, in Odisha it is a Rabi crop.

In Odisha, major oilseed crops like ground nut, sesamum, sunflower, mustard, while Niger also constituting a part of oilseed crop production by covering about 19 per cent and 7.5 percent of total area and production of oilseeds respectively. Koraput and Nabarangpur districts are now leading in Niger production in the state followed by Kalahandi, Keonjhar, Ganjam, Rayagada, Kandhamal. Niger is important in terms of its 32 to 40 per cent content of quality oil with 18 to 24 per cent protein in the seed. Niger oil is slow drying, used in food, paint, soap, and as an illuminant. It has an advantage of yielding oil and has good degree of tolerance to insect pests, diseases and attack of wild animals. There is less production of Niger crop in Odisha. It grows successfully without chemicals. So it is the need of forecasting the area where it can be grown, yield adequately & produce enough to meet the reqiurement. The main purpose of crop forecasting is to provide advance information on food crop production and food supply in the state. Forecasting cropping area that may be used under cultivation will help various stake holders to make policies on available land use and further food production capacity.

Various studies have been found under this area of research. Horie *et al.* (1992) studied on importance of yield forecasting of agricultural crops. Badmus *et al.* (2011) studied on forecasting the cultivated area and production of maize in Nigeria using ARIMA model. Zakari *et al.* (2012) forecasted Niger grain production and harvested area to help government for making policies with regard to relative price structure, production and consumption. Chinmayee *et al.* (2020) studied on the trend of jute production, area & yield in India for the period starting from 1950 to 2017 using ARIMA model.

Materials and Methods:

The secondary data on area, yield and production of Niger are collected for the state of Odisha (kharif and rabi seasons combined) for the period 1970-71 to 2019-20 from *Five Decades of Odisha Agriculture Statistics* published by Directorate of Agriculture and Food Production, Odisha.

An Autoregressive Integrated moving Average is a statistical model which is used to predict the future trends. The ARMA models, which includes the order of differencing (which is to stationarize the data) is known as Autoregressive integrated moving average (ARIMA) models. A non-seasonal ARIMA model is classified as an "ARIMA (p,d,q)" model, where, the parameters p,d,q are the non-negative integers where p is the number of autoregressive terms, d is the number of nonseasonal differences necessary for stationarizing the data, and q is the number of moving average terms. Thus, the ARIMA (p,d,q) model can be represented y the following general forecasting equation:

$$Y_t = \mu + \sum_{i=1}^{p} \phi_i Y_{t-i} + \sum_{j=1}^{q} \theta_j \varepsilon_{t-j} + \varepsilon_t$$

Where μ is a mean, $\phi_1, \phi_2, \ldots \phi_p$ and $\theta_1, \theta_2, \ldots \theta_j$ are the parameters of the model, p is the order of the autoregressive term, q is the order of the moving average term, and ε_t , $\varepsilon_{t-1}, .. \varepsilon_{t-j}$ are noise error terms.

Model identification:

The ARIMA model is fitted to stationary data i.e. having constant mean and variance. Staionarity of data can be tested by using Augmented Dickey-Fuller test. If it is not stationary then it should be converted into stationary series by differencing the data at suitable lag. Usually, the data is stationarized after 1 or 2 differencing. After stationarizing the data, the Auto Correlation Function (ACF) and Partial Auto Correlation Function (PACF) plots are used to identify tentative Auto Regression (AR) and Moving Average (MA) orders. Various tentative models based on identified AR and MA orders are fitted and parameters are estimated. After fitting the tentative models for a variable (area/yield/production) the estimated coefficients are tested for the significance and the normality and independency of the residuals of the fitted models are checked by using Shapiro-Wilk's test statistic and Box-Ljung test statistic respectively. The models having all the estimated coefficients significant and satisfying the normality and independency of the errors are now compared on the basis of model fit statistics like mean absolute percentage error (MAPE), root mean square error (RMSE) and Akaike's Information criteria corrected (AICc). Then the model having the lowest value of these model fit statistics is considered to be the best fit model for the variable.

The model fit statistics like MAPE, RMSE and AICc are mathematically as follows:

Mean absolute percentage error: $\frac{100}{n}\sum_{t=1}^{n}\left|\frac{y_t-\hat{y}_t}{y_t}\right|$

Root mean square error (RMSE): $\sqrt{\frac{\sum_{T=1}^{n}(\hat{y}_t-y_t)^2}{n}}$

where $\hat{y}_t$= forecasted value, y_t= actual value and n = number of times the summation iteration happens

Akaike's information criteria corrected: AIC + $\frac{2K^2+2K}{n-k-1}$

Where AIC is the Akaike's Information criteria, k denotes the number of parameters and n denotes the sample size.

The model with lowest RMSE, MAPE and AICc values is selected as the best fit ARIMA model among selected tentative models and it is taken for forecasting.

Results and Discussion:

The data on area, yield and production of Niger crop was tested for the presence of stationarity by using Augmented Dickey Fuller test and the results are presented in table -1. The test results confirmed that the data was not stationary and made stationary by differencing at lag 2.

Table 1: Test of stationarity of data on area, yield and production of Niger in Odisha

Variable	Original series		First order differenced series		Second order differenced series	
	ADF test statistic	P value	ADF test statistic	P value	ADF test statistic	P value
Area	-2.1488	0.5146	-2.224	0.08	-2.444	0.02
Yield	-2.0602	0.5502	-4.105	0.012		
Production	-1.8503	0.6343	-4.141	0.01115		

In the next step the order of AR and MA terms such as p and q were identified using the ACF and PACF plots shown in figures 1, 2 and 3. Different tentative models were identified using the orders of AR and MA terms.

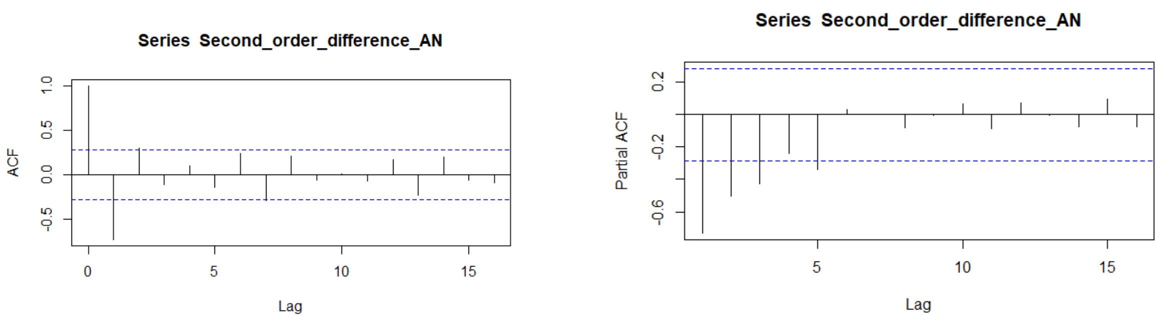


Figure 1: ACF and PACF plot of second order difference of area under Niger

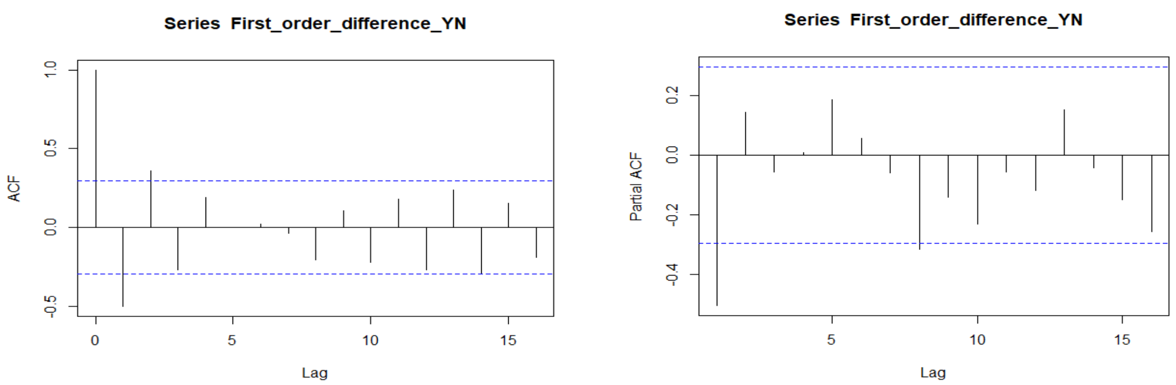


Figure 2: ACF and PACF plot of first order difference of yield of Niger

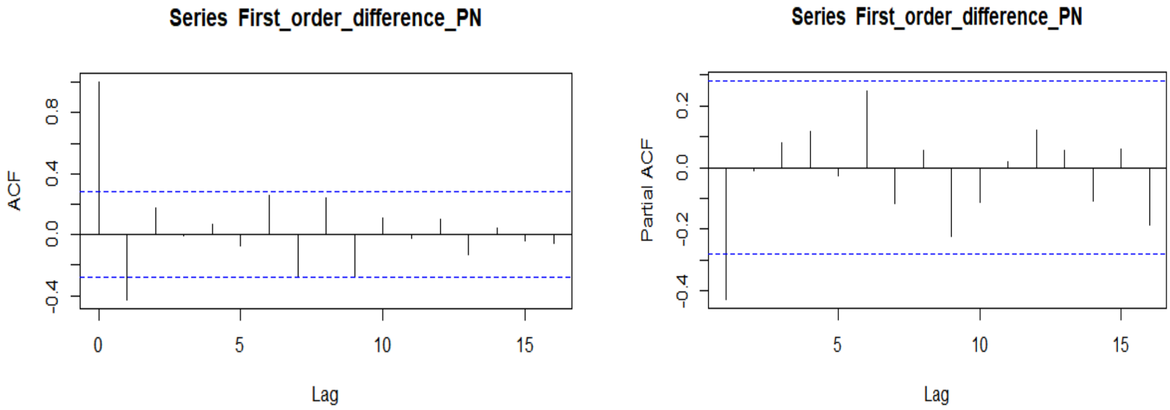


Figure 3: ACF and PACF plot of first order difference of production of Niger

The tentative models of area and their estimated coefficients along with error measures are shown in the table-2. The study of the table reveals that ARIMA(0,2,2) without constant model has all the estimated coefficients significant.

Table 2: Parameter estimates of the ARIMA (p,d,q) model fitted to area under Niger in Odisha.

ARIMA(p,d,q)	Constant	ϕ_1	ϕ_2	ϕ_3	θ_1	θ_2	θ_3
0,2,3	----	----	----	----	1.6495** (0.1452)	0.9249** (0.2678)	0.1801 (0.1636)
1,2,2	----	0.2315 (0.2049)	----	----	1.4141** (0.1873)	0.5346** (0.1699)	----
0,2,2	**----**	**----**	**----**	**----**	**1.5782** (0.1289)**	**0.6805** (0.1184)**	**----**
3,2,1	----	0.8682** (0.1645)	0.5138 (0.2067)	0.2358 (0.1538)	0.7635** (0.1083)	----	----
2,2,2	----	0.1432 (0.2096)	0.2534 (0.1708)	----	1.8076** (0.1960)	0.8916** (0.2028)	----

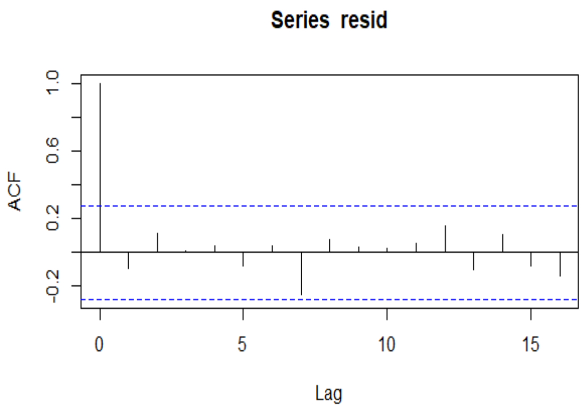
Figure inside the parentheses represents the standard error of thr parametric estimators, '*'- at 5% significance level, '**'- at 1% significance level

Table 3 shows the model diagnostics test and model fit statistics for the fitted ARIMA models. ARIMA (0,2,2) model satisfies both the test of normality and independency of residuals. The RMSE, MAPE and AICc are less for ARIMA (0,2,2) without constant model. Thus, this model is selected to be the best fit model for production of Niger crop. Figure 4 also shows that none of the autocorrelations and partial autocorrelations of residuals are significant. This furthers confirms the selection of the respective best fit models.

Table 3: Model fit statistics of the ARIMA (p,d,q) model fitted to area under Niger in Odisha

ARIMA(p,d,q)	Shapiro-wilk test		Box Ljung test		AICc	RMSE	MAPE
	W	p-value	x-squared	p-value			
0,2,3	0.87471	7.761e-05	0.01589	0.8997	433.57	19.121	9.409
1,2,2	0.87148	6.23e-05	0.022257	0.8814	433.63	19.125	9.452
0,2,2	0.85847	2.645e-05	0.5025	0.4784	**432.28**	**19.301**	**9.426**
3,2,1	0.88737	0.0001887	0.057101	0.8111	436.02	19.115	9.359
2,2,2	0.89223	0.0002687	0.050938	0.8214	436.01	18.876	9.477

W - Shapiro-wilk test statistic   x-squared - Box – Pierce test statistic



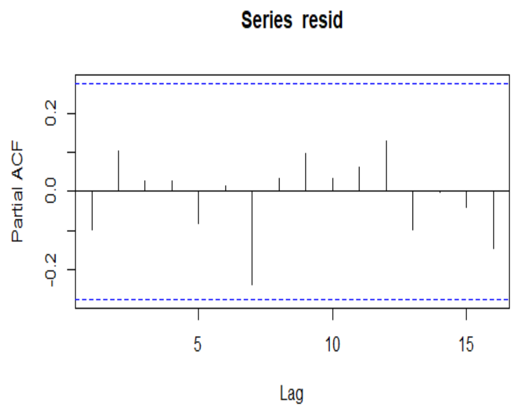


Figure 4: ACF and PACF of residuals from selected ARIMA (0,2,2) model for area under Niger

The tentative ARIMA models of yield and their estimated coefficients along with error measures are shown in the table 4. The study of the table reveals that ARIMA (1,1,0) with and without constant model has all the estimated coefficients significant**.**

Table 5 shows the model diagnostics test and model fit statistics for the fitted ARIMA models for yield of Niger. ARIMA (1,1,0) without constant model satisfies both the test of normality and independency of residuals. The RMSE, MAPE and AICc are less for ARIMA (1,1,0) without constant model. Thus, this model is selected to be the best fit model for production of horse gram crop. Figure 5 also shows that none of the autocorrelations and partial autocorrelations of residuals are significant. This furthers confirms the selection of the respective best fit models.

Table 4: Parameter estimators of the ARIMA (p,d,q) model fitted to yield of Niger for Odisha

ARIMA(p,d,q)	Constant	ϕ_1	ϕ_2	ϕ_3	θ_1	θ_2	θ_3	θ_4
1,1,0	**----**	**0.4909**** **(0.1220)**	**----**	**----**	**----**	**----**	**----**	**----**
2,1,0	----	0.4164** (0.1392)	0.1482 (0.1397)	----	----	----	----	----
1,1,1	----	0.7084** (0.1763)	----	----	0.2938 (0.2356)	----	----	----
0,1,4	----	----	----	----	0.5241** (0.1379)	0.3297* (0.1667)	0.1086 (0.1553)	0.3874** (0.1229)
1,1,0	2.0870 (4.3643)	0.4936** (0.1218)	----	----	----	----	----	----

Figure inside the parentheses represents the standard error of thr parametric estimators,
'*'- at 5% significance level, '**'- at 1% significance level

Table -5: Model fit statistics of the ARIMA (p,d,q) model fitted to yield of Niger in Odisha

ARIMA(p,d,q)	Shapiro-wilk test		Box Ljung test		AICc	RMSE	MAPE
	W	p-value	x-squared	p-value			
1,1,0	**0.944**	**0.02**	**0.195**	**0.658**	**517.57**	**44.97**	**9.819**
1,1,0(C)	0.945	0.021	0.215	0.6421	519.62	44.864	9.94
2,1,0	0.952	0.043	0.0006	0.9793	518.73	44.444	9.475
1,1,1	0.952	0.042	0.002	0.962	518.64	44.402	9.455
0,1,4	0.949	0.031	0.047	0.826	519.91	42.456	8.91

W - Shapiro-wilk test statistic x-squared - Box – Pierce test statistic

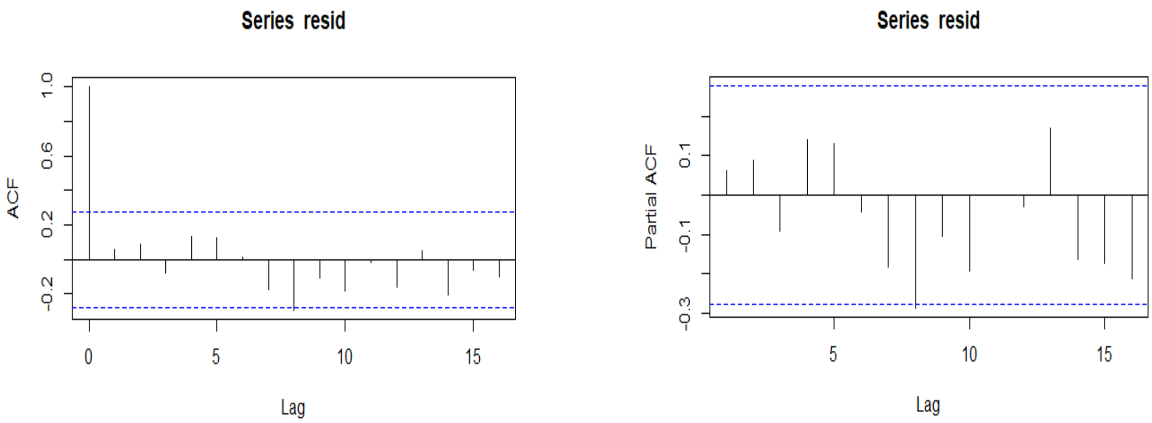


Figure 5: ACF and PACF of residuals from selected ARIMA (0,1,1) model for yield of Niger

The tentative models of production and their estimated coefficients along with error measures are shown in the table 6. The study of the table reveals that ARIMA (0,1,1), ARIMA (1,1,0) without constant and (1,1,0) with constant model has all the estimated coefficients significant.

Table 6: Parameter estimators of the ARIMA (p,d,q) model fitted to Production of Niger for Odisha

ARIMA(p,d,q)	Constant	ϕ_1	ϕ_2	ϕ_3	θ_1	θ_2	θ_3
1,1,0	**----**	**0.4169**** **(0.1276)**	**----**	**----**	**----**	**----**	**----**
0,1,2	----	----	----	----	0.4348** (0.1413)	0.1982 (0.1239)	----
0,1,1	----	----	----	----	0.3424** (0.1085)	----	----
2,1,0	----	0.421** (0.1414)	0.0094 (0.1402)	----	----	----	----
1,1,0	0.3229 (1.1714)	0.4177** (0.1276)	----	----	----	----	----

Figure inside the parentheses represents the standard error of the parametric estimates,
'*'- at 5% significance level, '**'- at 1% significance level

Table 7 shows the model fit statistics and model diagnostics test for the fitted ARIMA models for production of Niger. ARIMA (1,1,0) without constant model satisfies both the test of normality and independency of residuals and also having least AICc value. The RMSE, MAPE and AICc are less for ARIMA (1,1,0) without constant model. Thus, this model is selected to be the best fit model for production of Niger crop. Figure 6 also shows that none of the autocorrelations and partial autocorrelations of residuals are significant. This furthers confirms the selection of the respective best fit models.

Table 7: Model fit statistics of the ARIMA (p,d,q) model fitted to production of Niger for Odisha

ARIMA(p,d,q)	Shapiro-wilk test		Box Ljung test		AICc	RMSE	MAPE
	W	p-value	x-squared	p-value			
1,1,0	**0.908**	**0.0009**	**0.009**	**0.92**	**383.39**	**11.447**	**15.988**
0,1,2	0.911	0.001	0.0005	0.981	38514	11.382	15.75
0,1,1	0.906	0.0007	0.398	0.527	385.17	11.664	16.113
1,1,0	0.908	0.0009	0.008	0.926	385.6	11.438	15.648
2,1,0	0.909	0.0009	0.004	0.948	385.67	11.446	16.005

W - Shapiro-wilk test statistic   x-squared - Box – Pierce test statistic

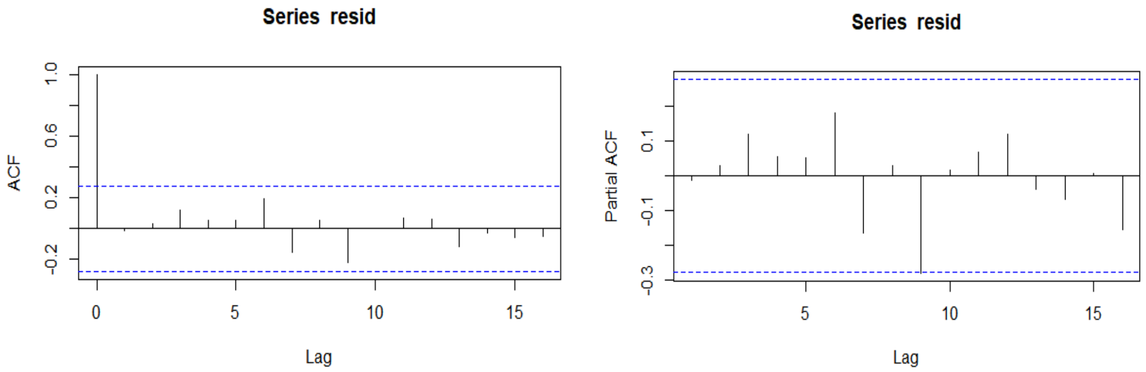


Figure 6: ACF and PACF of residuals from selected ARIMA (0,1,1) model for Production of Niger

In the table 8, the result of cross validation of the selected best fit ARIMA model by one-step ahead forecasting has been presented. The APE (absolute percentage error) of area under Niger is found to be in the range between 4 to 11 and the MAPE(mean APE) is found to be 10.205 for area of Niger crop. Similarly for yield the APE range is found between 0.nd 4 and MAPE is 1.982 and for production, APE range is between 3.6 and 13.6 and MAPE is 6.308. These results show that the selected ARIMA models are successfully cross validated.

Table 8: Cross validation of selected ARIMA models for area, yield and production of Niger in Odisha

Year	Area			Yield			Production		
	Actual	Predicted	APE	Actual	Predicted	APE	Actual	Predicted	APE
2015-16	63.93	66.88	4.614	352.72	360.61	2.2369	22.55	24.25	7.539
2016-17	63.75	55.72	12.596	355.45	357.27	0.512	22.66	23.54	3.883
2017-18	59.2	63.84	7.838	368.41	354.11	3.8815	21.81	22.61	3.668
2018-19	53.18	61.47	15.589	366.86	362.05	1.3111	19.51	22.16	13.583
2019-20	53.04	47.53	10.388	375	367.62	1.968	19.89	20.46	2.866
MAPE	10.205			1.982			6.308		

The appropriate ARIMA models which are represented in the previous tables were used to forecast the area, yield and production of Niger crop in Odisha for the years 2020-21, 2021-22 and 2022-23.

Table 9: Forecast values of Niger in Odisha for the year 2020-21 to 2022-23

Year	Area ('000ha)			Yield (kg/ha)			Production ('000 tonnes)		
	Forecast value	95 % confidence interval		Forecast value	95 % confidence interval		Forecast value	95 % confidence interval	
		Lower CI	Upper CI		Lower CI	Upper CI		Lower CI	Upper CI
2020-21	45.76	6.32	85.2	369	281.05	460.97	19.73	3.167	42.63
2021-22	42.22	-0.58	85.03	371	272.02	473.91	19.79	6.71	46.3
2022-23	38.7	-8.84	86.22	372	250.6	493.43	19.77	11.9	51.44

CI – Class Interval

Figures 7, 8 and 9 shows the actual, fitted and forecast values of area, yield and production of Niger in Odisha.

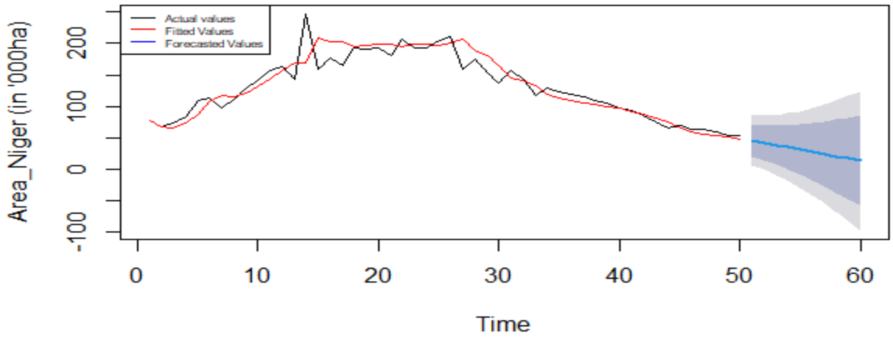


Figure 7: Actual with fitted and forecasted values of area under Niger from ARIMA(0,2,2) without constant model

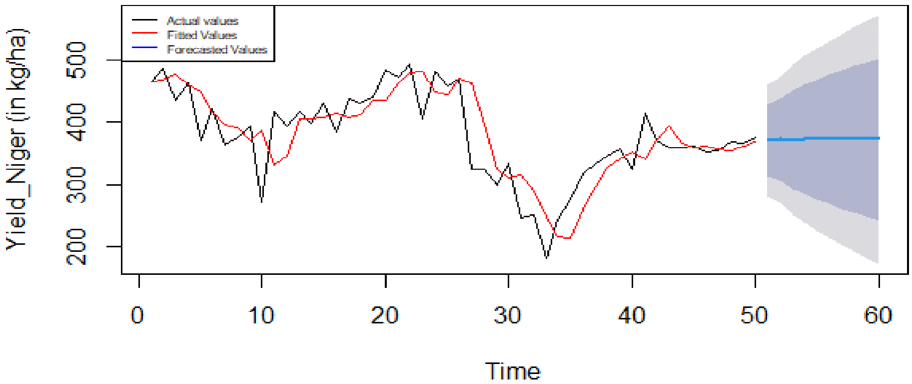


Figure 8: Actual with fitted and forecasted values of yield under Niger from ARIMA(1,1,0) without constant model

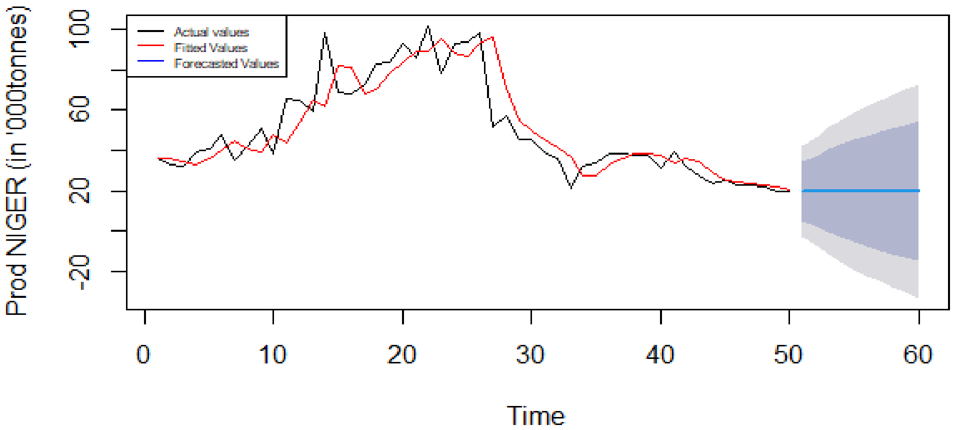


Figure 9: Actual with fitted and forecasted values of production under Niger from ARIMA(1,1,0) without constant model

Conclusion:

ARIMA (0,2,2) without constant model, ARIMA (1,1,0) without constant model and ARIMA (1,1,0) without constant model are found to be the best fit model for area, yield and production of Niger in Odisha. These selected models are used for forecasting of area, yield and production of Niger in Odisha. The forecast values shows that area under Niger is likely to decrease in future years, whereas, yield is likely to increase due to which the production of Niger in Odisha remain stagnant in future years with variation in lower and upper class interval of the forecast values.

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BIOCHAR: A VALUABLE SOIL AMENDMENT

Prashun Sachan*[1], Kritagya Gangwar[2], Drishty Katiyar[1],
Rahul Dev Behera[3], Prasun Sachan[4] and S. B. Pandey[1]

[1]Department of Soil Science and Agricultural Chemistry, C.S Azad University of Agriculture and Technology, Kanpur 208002, Uttar Pradesh, India

[2]Division of Soil Science and Agricultural Chemistry, ICAR-IARI New Delhi 110012

[3]Soil Science & Agricultural Chemistry), Krishi Vigyan Kendra, Bolangir, Odisha – 767002

[4]Department of Agronomy, C.S Azad University of Agriculture and Technology, Kanpur 208002, Uttar Pradesh, India

*Corresponding author E-mail - kushalsachan95@gmail.com

Abstract:

Soil mineral depletion is a major problem, mostly due to soil erosion and nutrient leaching. Adding biochar is a solution as biochar has been proven to improve soil fertility, promote plant growth, increase crop yield and reduce contamination. The effects of biochar on soil health, including physical, chemical and biological parameters of soil quality and fertility, nutrient leaching, salt stress, plant productivity and quality, and the effect of biochar on saline and heavy metal contaminated soils were discussed with assistance from various literatures that the soil is modified with biochar.

Biochar is the product of heating biomass in the absence or with limited air to over 250 °C, a process called carbonization or pyrolysis, also used to make charcoal. The material differs from charcoal or other carbon (C) products in that it is intended for use as a soil application or more A generally for environmental management in the current climate change scenario. Biochar is made using a special process to reduce contamination and retain the carbon properly, although it looks like regular charcoal. Organic materials such as wood chips, leaves, and dead plants are burned during pyrolysis in a container with extremely little oxygen. When the materials are incinerated, they emit very few polluting gases. The organic matter is converted into biochar during the pyrolysis process, a stable form of carbon that cannot easily escape into the atmosphere.

Biochar is black, very porous, lightweight, fine-grained, and has a huge surface area in terms of physical characteristics.

- Carbon makes up over 70% of its composition. Nitrogen, hydrogen, and
- Oxygen, among other elements, makes up the remaining percentage.

Definition According to the International Biochar Initiative (IBI), the most accepted and standardized definition is "a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment" *(IBI 2012).*

Definition by Lehman and Co-workers: "Biochar is a porous, carbonaceous material that is produced by pyrolysis of plant biomasses and is applied in such a way that the contained carbon remains stored as a long-term C sink or replaces fossil carbon in industrial manufacturing. It is not made to be burnt for energy generation".

Nomenclature of biochar and related material in comparison to pyrogenic C structure

Biochar: Biochar is the solid product of pyrolysis evolved for environmental management. IBI (2013) defines biochar as A solid material acquired by the thermochemical transformation of biomass in an oxygen-limited environment. Biochar can be adopted as a product by itself or as an ingredient in a blended product, with a scope of applications as a method of soil improvement, improving resource adopt efficiency, remediation, and/or safety against particular pollution, and as a pathway for greenhouse gas (GHG) abatement.

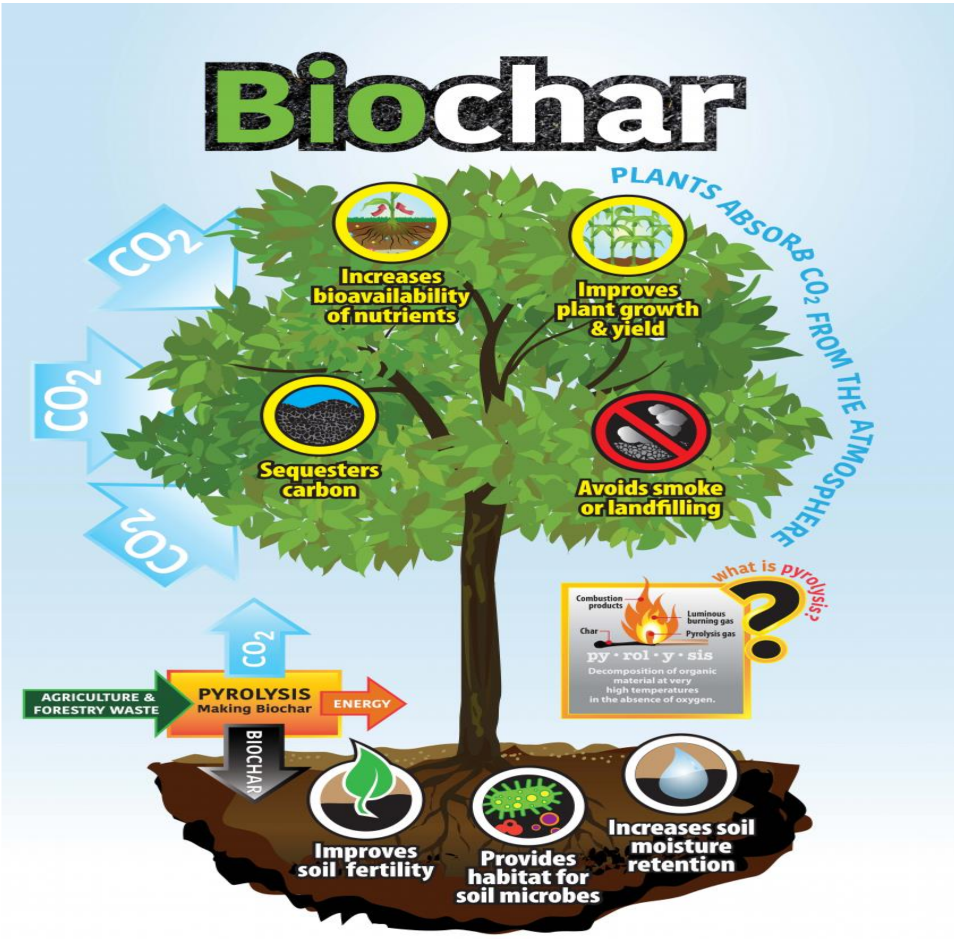
Hydrochar: Hydrochar is the solid product of hydrothermal carbonization (HTC) or liquefaction (sometimes referred to as HTC material), and differs from biochar owing to its production process and properties ***(Libra et al, 2011).*** It typically has higher H/C ratios and lower aromaticity than biochar, and little or no fused aromatic ring structures.

Pyrogenic Carbonaceous Material (PCM): PCM is introduced here as the umbrella term for all materials that have been fabricated by thermochemical transformation and encompass some organic C, such as charcoal, biochar, char, black carbon, soot, and activated carbon. The term refers to the material and not to the C atom.

Char: Char is described for the intent of this publication as the material produced by incomplete combustion procedures that appear in natural and man-made fires.

Charcoal: Charcoal is fabricated by thermochemical transformation from biomass (mainly but not exclus0ively wood) for energy generation. The term is sometimes exploited from the perspective of other uses, e.g., medicine, filtration, separation, etc. If processed additional by any form of activation, application of the term 'activated carbon' is proposed.

Biochar feedstocks and pyrolysis: A multitude of reviews and studies have focused on the potential advantages of employing biochar as a soil amendment. Pyrolysis and gasification of biomass are pioneered technologies for the production of biofuels and synthesis gas. However, the commercial application of biochar as a soil conditioner is still in its infancy. The effect of biochar as a soil improver on crop productivity is variable, mostly due to interactions and algorithms involved in the application of biochar to a soil that is not yet fully understood. Currently, Japan has the largest market for biochar products; approximately 15,000 tons/year are traded annually for land use. The pyrolysis procedure affects the quality of the biochar produced and its potential value to agriculture in the terminology of soil performance or carbon sequestration. The temperature and time that the biomass is in the pyrolysis furnace, together with different types of raw materials, determine the type of product. Starting material and procedure conditions influence the characteristics of the biochar produced. Thermal profile and feed selection, as well as geographic discrepancies in soil type and climate, are some of the main sources of variability when it comes to biochar benefits as soil improvement. Raw materials currently used on a commercial scale or in research facilities include wood waste, crop residues (including straw, nut shells, and rice husks), switchgrass, bagasse from the sugar cane industry, chicken manure, dairy fertilizer, sewage sludge, and paper sludge. Biomass energy crops processed through slow pyrolyses, such as grain and wood, along with agricultural waste, including wheat straw and peanut shells, yield a char suitable for soil amendment. Green waste such as plant clippings and grass clippings as well as sewage sludge were also used as soil improvers.



Source-https://nfs.unl.edu/about-biochar

Table 1: Application of biochar and soil response

	Plant Type	Source of Biochar	Rate of Application	Influences on Soil Parameters	Reference
Vertisol silt loam	Sorghum	Acacia	10 Mg ha^{-1}	High soil C, exchangeable K^+, Ca^{2+} and CEC	Deng *et al.* (2017)
Sandy Loam	Wheat and maize	Biochar	5–20 Mg ha^{-1}	Decreased pH, bulk density, soluble Na, increased CEC, OM, total N, available P, K, Zn, Cu, and Fe in soil	Mausa *et al.* (2017)
Sandy loam	Potato (*Solanum tuberosum* L.)	Mixture of hardwood	5% (w/w)	Decreased Na+/K^+ ratio	Akhtar *et al.* (2015)
Clay loam	Maize	Maize straw	10–30 Mg ha^{-1}	Increased available P, K, total N	Xiao *et al.* (2016)
Aqui-Entisol	Maize	Wheat straw	Wheat straw	Decreased NaCl content in leaf, increased P and K	Lashari *et al.* (2015)

Impact of biochar on soil properties

Soil physicochemical properties have a substantial effect on nutrient retention and uptake, plant growth and productivity, and microbial activities. Studies have revealed that biochar can improve soil physicochemical and biological properties and generate a suitable environment for plant roots, nutrient uptake, and plant growth. Biochar application affects soil water infiltration, WHC, aggregate stability, soil aeration and porosity, bulk density, soil hardening, pH, CEC, and nutrient cycling, among others.

Impact of biochar on soil porosity

Porosity indicates the pore space between soil particles and affects soil aeration, nutrient retention, and water movement within the soil. Porosity differs between different soil textures, with clay soils having the highest porosity and sandy soils having the lowest. Biochar can increase soil porosity by decreasing soil pack and bulk density and increasing soil aggregation. The utilization of Zhang *et al.* (2017) with biochar increase capillary and total soil porosity by 23 and 24%, respectively, compared to unmodified soil (control). Studies illustrated that biochar did not soil porosity uniformly even when applied at the same rate, likely a consequence of differences in soil type and soil texture classes in different studies. In general, coarse-grained soils illustrate a substantial improvement in porosity after biochar application compared to fine-grained soils.

Soil Water Holding Capacity (WHC)

Soil water retention or WHC indicates the maximum amount of water that a soil can retain or hold. Several field studies have revealed that biochar application enhances soil water retention by positively impacting soil porosity space between biochar particles and other soil structural and structural properties. In addition to the porosity between biochar particles, biochar particles also have an intrapore space (space within the particles) that provides further space for water retention or storage. Soil water infiltration rate and moisture content heightened significantly after biochar application. The amount of biochar applied also impacts the moisture content of the soil. For example, Ndor *et al.* (2015) applied sawdust and rice husk biochar at 510 Mg ha^{-1} each and recorded a 10.8% increment in soil moisture content compared to no biochar application.

Soil organic matter and soil organic carbon content

Soil organic matter (SOM) is a critical factor affecting soil health, microbial activity, nutrient cycling, and water retention. Many studies have shown that biochar application can increase soil C, improve WHC and increase aggregate formation and stability. However, these reactions are highly dependent on the raw materials used, pyrolysis conditions and application rates, and the soil types to which biochar is applied. Biochar supplementation increases soil organic carbon (SOC), but like other physical and chemical parameters of soil quality, enhances are strongly correlated to the sort of feedstock and the temperature exploited in the pyrolysis process. Biochar produced at low pyrolysis temperature usually has a higher labile C content than biochar produced at the higher temperature. According to Jiang *et al.* (2016), the addition of biochar can alleviate native SOC degradation by adsorbing it on its surface. Thus, it can decrease the amount of native SOC available for enzymatic degradation. However, easily degradable C can detach from the surface of biochar and stimulate microbial activity.

Impact of biochar on soil bulk density

Soil bulk density is an indicator of soil health, compaction, and soil aeration, and affects water infiltration, plant root depth, and nutrient movement. High bulk density trays have a lower capacity than high bulk density trays. This can increase water absorption and cause high resistance of plant roots to soil penetration. It is hypothesized that at least two mechanisms are responsible for the reduction in soil bulk density after biochar application. First, the soil has a higher bulk density (~1.25 g cm^{-3}) than biochar (0.6 g cm^{-3}). The utilization of biochar can reduce the bulk density of the soil through a dilution effect. Second, biochar can alleviate soil bulk density in the long term, in part owing to the intricate interactions it makes with soil particles that further enhance soil aggregation and porosity.

Impact of biochar on soil pH

Soil pH affects the mobility and accessibility of different nutrients and chemical elements in the soil. Generally, utilization of biochar in the soil increases the soil pH, although modifications are vigorously driven by the soil type, feedstock material, and the liming value of biochar.

Cation Exchange Capacity (CEC)

CEC is one of the important properties of soil affecting soil fertility and adsorption of mineral nutrients and ions such as sodium (Na^+), Ca^{2+}, Mg^{2+}, K^+, and NH_4^+. Although CEC is a natural and inherent characteristic of every soil, it cannot be conveniently altered through management. Biochar additives can increase the CEC of the soil, which could be due to the existence of a potent carboxyl and phenolic function. ***Ndor et al., (2015)*** observed a 21% increase in soil CEC after application of 5 Mg ha^{-1} biochar made from rice hulls and sawdust, and a 44 and 57% CEC increase at 10 Mg ha^{-1}. Each biochar was adversely charged on the surface of biochar particles compared to non-biochar application groups.

Impact of biochar on nutrient availability

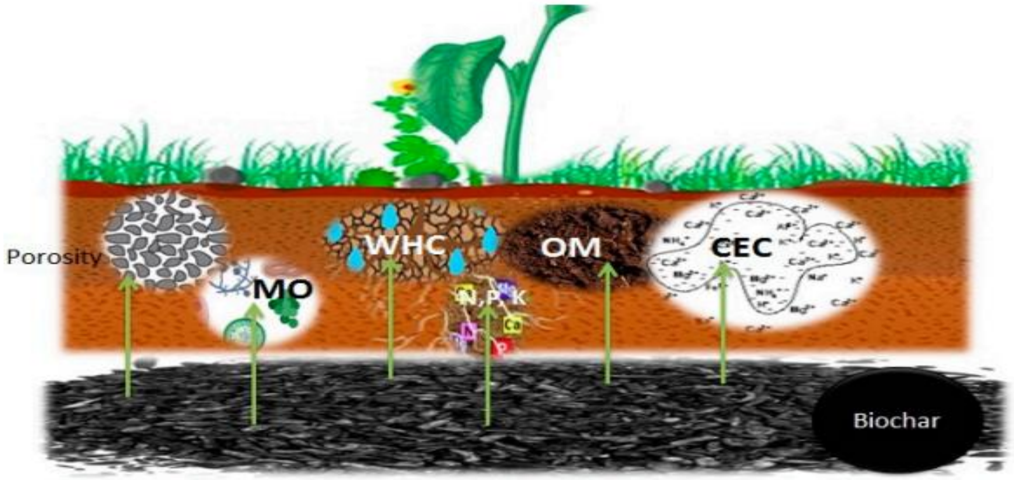
Biochar produced by pyrolysis encompasses aromatic C and small amounts of N, P, K, Ca, Mg, S, and other nutrients anticipated for plant growth. Biochar improves soil physical and chemical properties such as CEC and soil surface oxidation, resulting in an increment in the accessibility of plant nutrients and their retention in the soil. Soil incorporation of biochar has listed a positive influence on soil C-stability, particularly in soils with less native OM. Usually, the solubility of inorganic P is low because it questionnaires mineral precipitates with $Ca^{2+,}$ aluminum (Al^{3+}), and iron ($Fe^{3+)}$ or firmly sorbs to the soil mineral phase (Al and Fe oxyhydroxide). However, the past investigation has demonstrated that biochar changes the P available in soil by (a) acting as a P source itself, (b) altering P solubility through differences in soil pH, (c) adsorption, and Desorption of specific chelates altered and (d) promotion of P-soluble bacteria (Gao *et al.,* 2016). Therefore, the application of biochar is emerging as a relevant practice to effectively remove the use of synthetic fertilizers and increase NUE. Incorporation of corn residue biochar into calcareous soil at 12% (w/w) heightened total N up to 41%, available P up to 165%, K up to 160%, and manganese (Mn), Fe, Zn, and Cu up to 21, 17, 42 and 10% respectively compared to the unaltered soil (control).

Impact of biochar on nutrient leaching

Nutrient leaching is the main difficulty in agricultural systems. Mobile nutrients move down below the root zone of plants and consequently become unavailable for plant uptake. Biochar can considerably reduce nutrient leaching by increasing nutrient retention, soil C, soil WHC and microbial activity. It is a valuable technique to sorb nutrient problems as N and P to mitigate surface water contamination. Properties of biochar such as high surface area, porosity, charge density, and CEC are advantageous in increasing the retention of nutrients and other organic molecules. However, the sorption capability of biochar also relies on the input materials and the pyrolysis temperature. For example, biochar obtained from wood has a higher phosphate adsorption capacity than biochar generated from straw residues.

Effect of biochar on soil microbial activity

Soil microorganisms play important roles in OM decomposition, nutrient recycling, soil structure maintenance, pest and disease suppression, and secretion of plant growth promoters. Biochar application can affect soil microbial activity and community structure (Figure) through its important properties such as pore space, surface area, porosity, minerals, surface unpredictable organic compounds, functional groups, free radicals, and pH. Biochar contains K^+, Mg^{+2}, Na^+, N, P, and other nutrients, which, once released into the soil solution, can have long-term positive impacts on microbial growth. In addition, some bacteria and fungi, which are smaller than the pore size of certain biochar, can prevent these pores In addition, soluble substances such as sugars, alcohols, acids, ketones, and water molecules stored in mesopores and micropores of biochar can promote microbial activity and modify microbial abundance and composition in soil.



(Biochar increase porosity, microorganism, WHC, Organic Matter, Nutrients, and CEC of Soil)

Figure 2. Beneficial effects of biochar on soil (Source: Alkharabsheh *et al.*, 2021)

Impact of biochar on salt-affected soils

Soil salinity extremely affects plant growth and yield, particularly in arid and semi-arid areas of the world. Internationally, salt-affected areas occupied 1 billion ha, and it is estimated that this area will proceed to expand owing to global climate modification and poor land and water resource management. There are three types of saline soils namely saline, sodium and saline soils. Saline soils have a high concentration of soluble salts, while sodium soils encompass a high concentration of Na^+ ions adsorbed on cation exchange sites. Saline soils possess characteristics of both, with exchangeable sodium > 15% and electrical conductivity > 0.4 S m-1. Salt-loaded soils can be cultivated if relevant management practices or quantifies are adopted. The application of organic modifications in salinity-affected soils can have beneficial impacts on plant growth by modifying some soil physio-chemical properties. Recent studies have demonstrated that the inclusion of biochar supplements in saline soils has attracted great attention from agronomists. The utilization of biochar on saline soils heightened the K^+, Ca^{+2}, Mg^{+2}, Zn^{+2}, and Mn^{+2} concentration owing to a concomitant increment in CEC, surface area, structure, and porosity of soils, and stability of organic molecules. In saline soils, a high Na^+ concentration impairs the uptake of K^+ by plants. However, adding biochar can reverse this scenario and improve K^+ absorption. Phosphorus availability is higher at a soil pH of 5.57, but the pH of saline soils is >7, which reduces P availability. However, biochar application can increase P availability in saline soils due to its inherent fertilizer P-value. In addition, it can increase P availability by generating favorable conditions for the increment of soil bacteria (Flavobacterium, Pseudomonas, and Thiobacillus) that can solubilize unavailable P in the soil.

Impact of biochar on soils contaminated with heavy metals (HMs)

Soil contamination with HMs such as mercury (Hg), lead (Pb), cadmium (Cd), arsenic (As), titanium (Ti) and lithium (Li) is a major international problem. Due to their high mobility and bioavailability, heavy metals can conveniently enter and accumulate in the food chain, leading to neurological and immunological diseases at multiple trophic levels. Studies have revealed that the use of organic materials with high pH, CEC, surface area, and porosity such as biochar can improve contaminated soils due to their efficiency in adsorbing HMs from soils. The ionic forms of metals dissolved in the soil solution are bioavailable to plants. Biochar adsorbs the metal ions from contaminated soils due to its stronger sorption sites and high affinity for metal ions (Sizmur *et al*, 2017). Besides the process, both acidic functional groups (carboxyl, hydroxyl, lactone, and carbonyl groups) and basic functional groups (pyrone and ketone) play significant roles in the complexation (binding) of HMs on the surface of biochar and its inner pores (Beesley *et al.*, 2015). For example, HMs such as Cu, Zn, Cr, and Pb can react with carbonate, phosphate, and oxide ratios of biochar and precipitate on the surface of the biochar as insoluble carbonate and phosphate salts (Nejad *et al.*, 2017). The exchange of ionic species from the soil matrix at the surface of biochar can also immobilize the target metal species in the soil (Wang *et al.*, 2018). Similarly (Li *et al.*, 2018), the application of soybean (*Glycine max* L.) biochar at an incidence of 3% (w/w) to an As-contaminated soil reduced as the bioaccumulation in the rice plants decreased by 88% declined.

Table 3: Reduced uptake of different chemicals after biochar application into soil

Biochar Type	Pollutant	Plant Type	Reference
Rice straw	Cd	Rice	Zheng *et al.* (2016)
Pinewood	Pb	Maize	Ogundiran *et al.* (2015)
Soybean residues	Cd	Rice	Li *et al.* (2018)
Sugar cane bagasse	Cr	Mash bean (*Vigan mungo* L.)	Bashir *et al.* (2018)
Cotton sticks	Ni	Spinach	Younis *et al.* (2016)

Biochar for improving Water Use Efficiency (WUE)

Soil amendments such as biochar can improve WUE in the agricultural system under increasingly water-limited conditions. Pot and field trials have shown that biochar retains soil water, increases WHC, improves water availability for plants, enhances nutrient uptake, and supports root growth in the soil.

Impact of biochar on Nitrogen Use Efficiency (NUE)

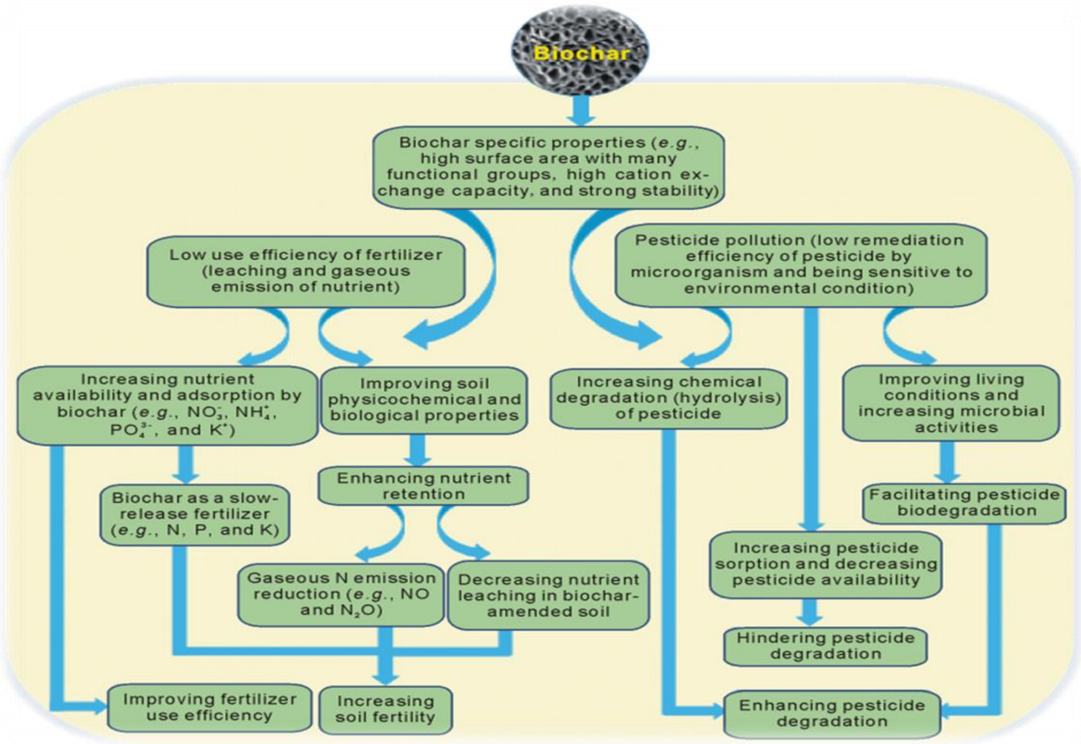
An essential factor of multitude of proteins, vitamins, amino acids, alkaloids, plant hormones, chlorophyll, ATP (adenosine triphosphate), and DNA, N is vital to in greater amounts than any other plant nutrient. However; Much of the applied N is lost from agricultural soils owing to various factors, reducing both crop yields and NUE. Nitrogen use efficiency can be improved either by increasing the uptake of applied N by the plant and its translocation to economical sections of the plants by reducing N losses from the soil system, or both ***(Xia et al, 2016).*** Research has demonstrated that the purpose of biochar with N fertilizers enhances fertilizer NUE and increases crop yields while reducing N losses ***(Huang et al, 2018).*** Again, beneficial attributes of biochar in the terminology of high surface area, porosity, CEC, and a plethora of acidic and basic functional groups play a crucial role in reducing N-losses from soils.

Impact of biochar on plant growth and physiological traits

Plant growth relies on a sufficient concentration of nutrients that are accessible in the soil solution and readily assimilated by the plants. A paucity of nutrients can alleviate plant growth and yield. Studies have demonstrated that biochar can increase the availability of C, N, Ca, Mg, K, and P to plants as biochar is itself a nutrient source. In addition, it can absorb nutrients and then slowly release them, improving the efficiency of nutrient use. Studies have shown that biochar supplements considerably improved growth and biomass in multiple plant species. Biochar application increased corn stomata conductivity, resulting in a higher prevalence of photosynthesis and increased production of total soluble sugars in soybean plants compared to unmodified soil control (Qian *et al.*, 2019). Higher chlorophyll and N levels were quantified in wheat plants after biochar application compared to unmodified soil.

Advantages of biochar application

1. **Less emission of greenhouse gases in the air:** Biochar is a stable product that could stay in the soil for numerous years, eventually reducing the emission of greenhouse gases from the burning of biomass.
2. **Water retention:** Biochar has moderate porosity that enhances the water retention of soil. In this way, it facilitates soil in growing plants and vegetables.
3. **Carbon sequestration:** The conversion of biomass into biochar does emit carbon in the air but it is less as compared to the combustion of biomass. Hence biochar embodies carbon sink in soil.
4. **Agricultural productivity:** The utilization of biochar in the soil increases agricultural productivity and promotes agricultural resilience.
5. **Reduction in soil acidity:** One of the main advantages of biochar is it assists in decreasing soil acidity which impedes crop production.



Source- Yang ding *et al.* (2017)

Conclusions:

Biochar modification has attracted considerable research interest due to its abundant use and broad potential, which encompasses increasing crop production by optimizing soil fertility, reducing greenhouse gas emissions, and increasing soil carbon sequestration. Using biochar for environmental and agricultural systems is a feasible alternative that can enhance soil quality, improve carbon sequestration, and alleviate various agricultural wastes. Biochar can also be used to remediate degraded landforms, thus offering many long-term environmental, agricultural, and economic benefits. However, in the mandate to promote the application of biochar as an emerging change, multiple research, development, and demonstration on the production and utilization of biochar are very important.

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PHYTOPHTHORA STEM BLIGHT OF PIGEON PEA [*CAJANUS CAJAN* (L.) MILLSP.]- AN OVERVIEW

Prince Kumar Gupta*, Manpreet Kaur and Rajshree Verma
Department of Plant Pathology, College of Agriculture,
G.B. Pant University of Agriculture and Technology, Pantnagar- 263145, Uttarakhand
*Corresponding author E-mail: princeguptapm@gmail.com

Abstract:

The pathogen, *Phytophthora drechsleri* f. sp. *cajani*, inciting Phytophthora blight (PB) is considered the most devastating disease-causing economical losses in pigeon pea (*Cajanus cajan*), especially when excessive rains fall within a short period and hot and humid weather persists during the crop season. The disease has also been reported in other countries. It was first reported in 1966 in India and is currently considered to be more important in short-duration pigeon peas than in traditional medium- and long-duration types. In this chapter, economic importance, symptoms, etiology, disease cycle, epidemiology, storage of pathogen, host range, and management options are updated for future priorities.

Keywords: Pigeon pea, Phytophthora stem blight, *Phytophthora drechsleri*, IDM

Introduction:

Pigeon pea [*Cajanus cajan* (L.) Millsp.], an often cross-pollinated, diploid, protein-rich legumes crop of the semi-arid tropics that is grown throughout the tropical and subtropical regions of the world. It is regarded as the fourth most important food legume after bean (*Phaseolus vulgaris* L.), field pea (*Pisum sativum* L.), and red gram (*Pisum sativum* L.). It provides a high-quality diet for human consumption as a primary source of protein (green seed- 21%, mature seed- 18.8%, and dhal- 24.6%), especially for the Indian subcontinent's vegetarian population. Additionally, it is also a key component of animal feed diets. Crop rotation of cereals with Pigeon pea increases the yield by embellishing soil nitrogen and also breaking the disease cycle of the pathogen. Pigeon pea is mostly suitable for low-fertile soil because of its permissiveness to heat and drought. In defiance of its hardy nature, it is being enervated by a range of harmful and devastating microbial pathogens posing significant reverberations on the yield and quality of the produce. More than 50 diseases caused by fungi, bacteria, viruses, nematodes, etc have been reported to affect the pigeon pea crop. Of the diseases reported to threaten production, the Phytophthora stem blight is considered the major important disease incited by *Phytophthora cajani*. This chapter has been prepared to assist in the field diagnosis of Phytophthora stem blight of pigeon pea. Furthermore, economic importance, host range, symptomatology, disease cycle, and integrated disease management are included to make the book chapter more useful to scientists, scholars, extension practitioners, and farmers.

Economic importance:

Phytophthora stem blight (PB), is considered the 3 rd potentially major disease of pigeon pea after Fusarium wilt and SMD (Sterility mosaic) incited by the fungus *Phytophthora drechsleri* Tucker f. sp. *cajani.* (Pal et al) (Williams et al., 1975; Kannaiyan et al., 1984). In India, the first suspected occurrence of the disease was reported in 1966 by William and his co-workers (1968). Since that time, the illness has spread to several pigeons' pea growing regions in Asia (Pal et al., 1970; Williams et al., 1975), Australia (Wearing and Birch., 1988), Africa, America (Kannaiyan et al., 1984), Dominican Republic, Kenya, Panama, and Puerto Rico (Nene et al., 1996). No longer ago, the recurrence of the disease become a major menace to the production and productivity of pigeon pea in the Deccan Plateau of India reported irrespective of cropping system, soil types, and cultivars (Pande et al., 2006; Sharma et al., 2006). Worldwide, the information regarding total losses caused by Phytophthora blight is not available, but it is axiomatic that the disease is of growing importance and can cause havoc in a susceptible cultivar. The Phytophthora blight is quite graver in short-duration (3-4 months) pigeon peas than in medium- and long-duration (5-10 months) traditionally cultivated cultivars. The effect of PB on grain yield depends on the onset of the disease with crop growth and disease incidence, both of which largely depend on weather conditions and inoculum levels of the pathogen.

Host range:

The pathogen, *Phytophthora drechsleri* Tucker var. *cajani* has a wide host range *viz;* lucerne, safflower, and skeleton weed (Cother, 1975), *Atylosia scarabaeoides* and *A. platycarpa* (wild pigeon pea) (Kannaiyan and Nene, 1985).

Symptoms:

The disease PB (Phytophthora blight) is mistaken for Fusarium wilt or a damping-off as general symptoms of both the diseases are similar causing seedlings to die suddenly (Table 1). Phytophthora blight symptoms have been described as stem rot (Pal *et al.*, 1970), stem canker (Kaiser and Melendez., 1978), root rot (Wearing and Birch, 1988), and stem blight (Williams et al., 1975; Amin et al., 1978; Kannaiyan *et al.*, 1980). Generally, the infection of the disease begins with the emergence of the seedling. Initially, the symptoms appear as water-soaked, dark brown to purple necrotic lesion on the primary and triplicate leaves (Figure 1 a) which later becomes enlarges in size and forms depression and girdles at the basal portion of the stem (Figure 2 a, b). Later the visible symptom extended to the aerial portion of the crop like leaves and branches which caused softening of the tissue and loss in turgidity resulting in desiccation of young plant. Due to softening of the stem or bark of mature plants, the whole plant collapsed easily from the point of infection by the wind which ultimately leads to the death of the plant. The phloem vessels show smoky discoloration (Figure 3 b) and xylem vessels remain healthy.

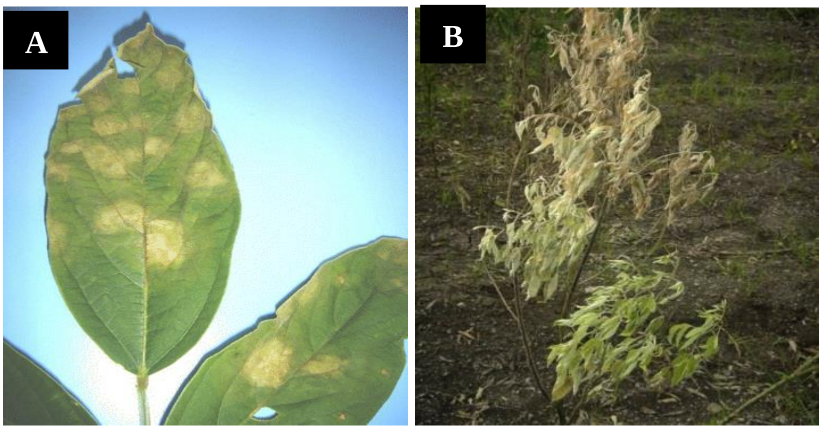

Figure 1: (a) water-soaked lesion on infected leaves (b) foliage blight appearance

Table 1: Symptoms differentiation of Phytophthora blight and Fusarium wilt

Growth stage	Phytophthora blight	Fusarium wilt
Seedling (Up to 30 days)	Young seedlings are killed within 3-10 days.	Young seedlings gradually wilt and die within 10-30.
Foliage (30-45days)	Water-soaked lesions on the leaves and whole foliage give a desiccated appearance.	Initially, loss of turgidity, slight chlorosis, and drooping of leaves.
Stem (45- >75 days)	Brown to dark brown lesions increase gradually and girdle the stem. The infected stems break easily at the lesion site.	Dark brown- purple streak band extending upward from soil level and usually seen only on one side of the stem. Browning of the xylem vessels in the internal symptom of wilt.
Root	It is also common to find stem and branches swollen at the base or else turning into a cankerous hyper tropical structure. The roots of infected plants are healthy and difficult to uproot.	Pinkish mycelial growth is seen on wilted plants part in humid conditions. The roots of the infected plants are dried and can be pulled easily.

Causal organism:

The causal organism of Phytophthora stem blight i.e., *Phytophthora drechsleri* Tucker var. *cajani* Pal, Grewal, and Sarbhoy was identified by Pal *et al.* (1970). Amin *et al.* (1978) identified the PB pathogen as *P. cajani*. Based on sporangia shape and size, formation of oogonium and oospore, temperature requirement, and pathogenicity of five isolates of pathogen, it was named

P. drechsleri Tucker f. sp *cajani* (Pal *et al.*) The use of forma specialis was considered appropriate according to the International Rules of Botanical Nomenclature, Article e 4 (Pandey *et al.*, 2011).

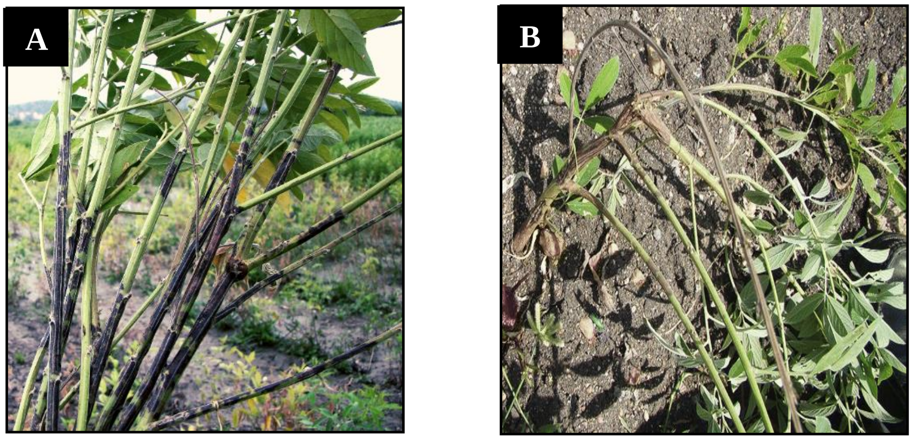

Figure 2: (a) Dark-brown lesion on stem (b) Stem gridling

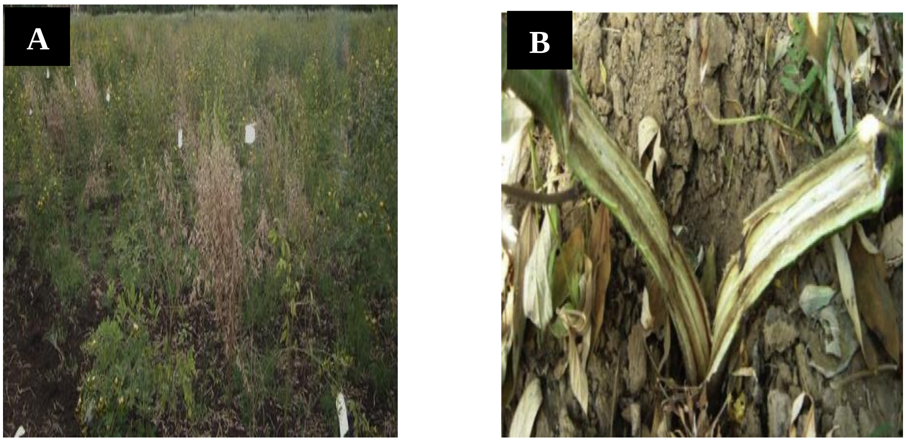

Figure 3: (a) Mortality in field (b) Smoky grey colour of phloem vessel

Pathogen identification:

Culture-specific traits like growth pattern, mycelium structure, and sporangial morphology are the most common differences amongst *Phytophthora cajani* isolates. The pathogen shows different growth patterns in different cultural media. The growth of circular colony with a rosaceous form on PDA (Figure 4 a), circular stoloniferous colonies with hyphae at the edge looks like aerial (corn meal), circular, slightly petaloid colonies with compact hyphae (oatmeal), while circular, petallate, and dull white colonies are formed on tomato juice agar and V8 juice agar media. The fungus hyphae are coenocytic and completely branched, except some have swell hyphae (Sharma *et al.*, 2018). The structure of fungus sporangium varied from ovoid, obpyriform to elongate, and non-papillate (Figure 4 b). The size of the sporangial ranged from 19.3 ± 2.6 to 28.4 ± 4.9mm (length) and 11.2 ± 0.8 to 18.5 ± 0.3mm in breadth. The morphological identity of the pathogen was described in the manual on Phytophthora (Gallegly and Hong, 2008) that was based on sporangial morphology *P. cajani* produced larger sporangia and undifferentiated sporangiophores compared with *P. drechsleri* (Amin *et al.,* 1978). The homothallic nature of *P. cajani* that differentiated it from *P. drechsleri*, (heterothallic) was reported by Savage *et al.* (1968).

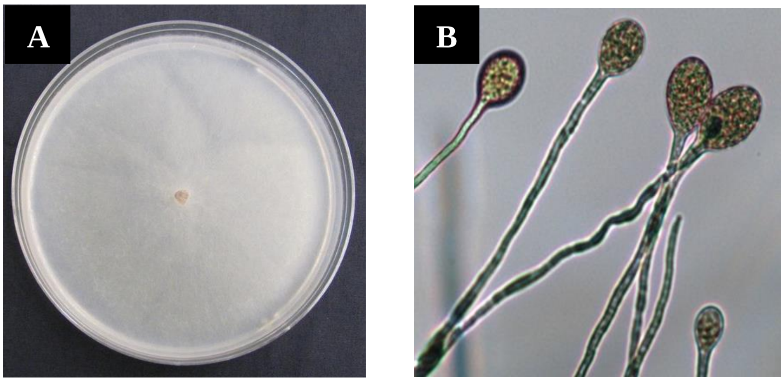

Figure 4: (a) pure culture of PB of pigeon pea (b) *Nonpapillate sporangia*

Molecular characterization:

The use of advanced molecular detection technologies to validate the pathogen's identity has become crucial. The internal transcribed spacer (ITS) sequence of 5.8S rDNA from the 14 isolates was amplified and sequenced to confirm the *P. cajani* at the molecular level. The Phytophthora database (http://www.phytophthoradb.org) was used to evaluate the sequences using BLASTn. The isolates identified as *P. cajani* was confirmed by the BLAST result. The sequences were stored to GenBank (accession nos. KJ010534 to KJ010538 and KJ622200 to KJ622208). The pairwise nucleotide sequence identity matrix revealed that the isolates shared 99 to 100 percent sequence identity. Based on nucleotide sequences of the ITS region, the phylogenetic relationships between the 14 *P. cajani* isolates and other Phytophthora species were found to clump together in the same clade (Sharma *et al.,* 2015).

Disease Cycle:

The pathogen is soil-born and may survive in the resting stage as dormant mycelium and in infected plant parts or debris as oospores. Under the congenial environmental condition, the primary infection spread from oospores when it comes in contact with the host plant through rain splash and irrigation channels. The secondary spread occurred by zoospores from sporangia under proper moisture and humidity.

Host-Pathogen Interaction

Phytophthora drechsleri is known to secrete elicitins which are small polypeptide chains composed of different amino acids. The pathogen produces several isoforms of elicitin with various levels of toxicity (Huet et al. 1992). Elicitin induces tissue necrosis that has been correlated with histological alterations, rapid electrolyte leakage, the release of reactive oxygen species (ROS), changes in protein phosphorylation, chloroplast break down, and collapse of disorganization of parenchyma tissue in the host plant (Pernollet *et al.*, 1993).

Resistance gene against stem blight has not so far been discovered due to the frequent evolution of new pathotypes, the coexistence of different pathotypes in the same location, and the cross-pollination nature of pigeon pea. Systematic research is needed to elucidate the biochemical, physiological, and molecular facets of host-pathogen interaction.

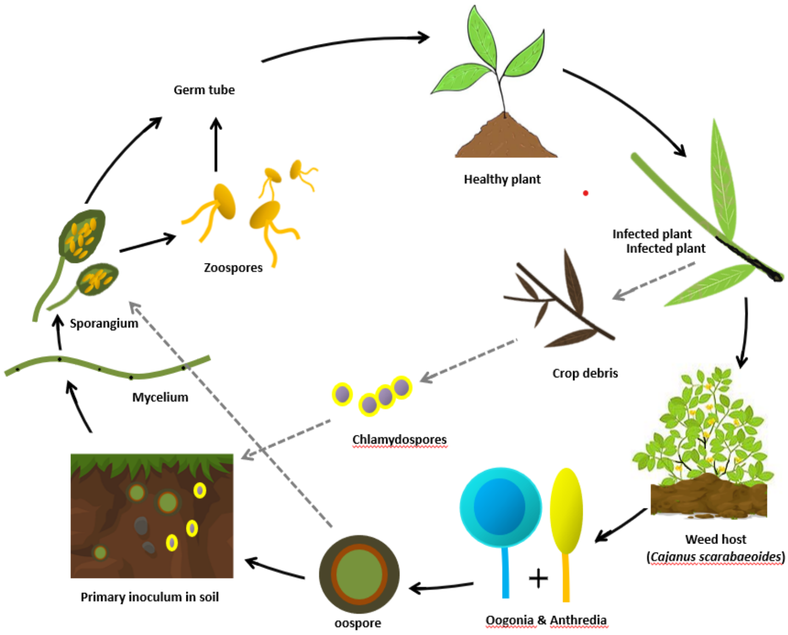

Figure 5: Disease cycle of *Phytophthora drechsleri* inciting Pigeon pea stem blight

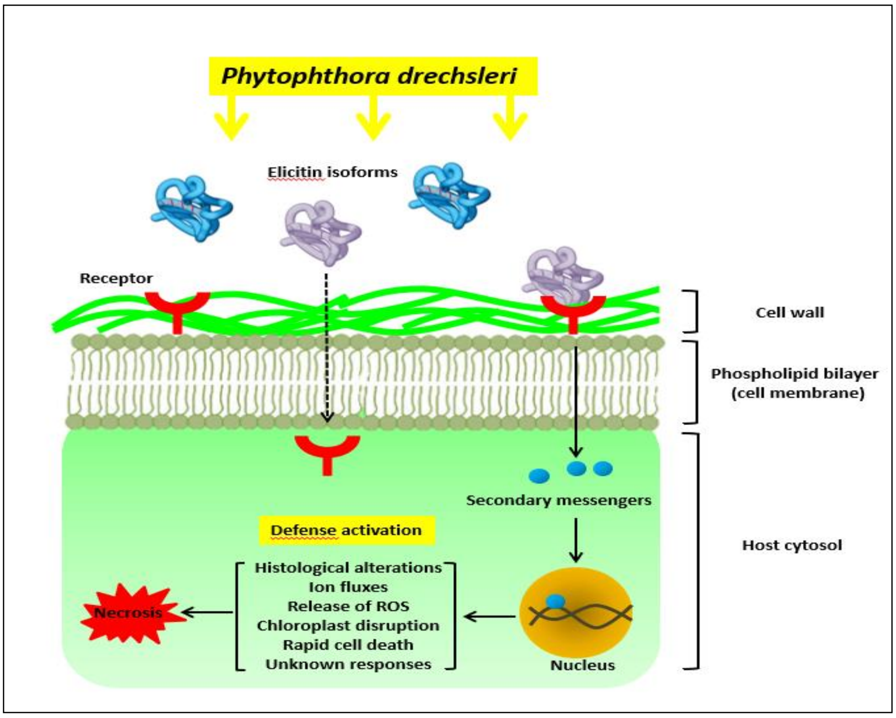

Figure 6: Molecular basis of host pathogen interaction

Epidemiology and Disease development:

The development and spread of the disease are enhanced and favoured by poor soil drainage and low-lying fields (Williams *et al.*, 1975). A short shower of heavy rains and the prevalence of hot weather (up to 30°C) during July - September causing leaf wetness for almost 7-8 hours favors the rapid and intense progress and spread of the disease. The zoospore of the fungus is considered the primary source of inoculum and wind disseminates inoculum over a short distance during the rain (Bisht, 1985). The wild pigeon pea relative *Cajanus scarabaeoides* var. *scarabaeoides,* is considered a host of the blight pathogen till the next cropping season (Agarwal and Khare, 1988; Bisht, 1985). Day and night also influence the progress of the disease. The rapid incidence and development of PB were observed during the night and were reported by Singh and Chauhan (1985). The maximum (28 to 40°C), minimum temperature of 12-24°C along with RH 75 to 96%, and rainfall of 300 mm for a week ultimately progress the development of the disease (Sharma *et al.*, 2006; Pande and Sharma, 2010). Alfisol soil is found more suitable for disease progress than vertisol soil. The absence of potassium (K) and a higher dose of nitrogen in soil enhanced the disease incidence (Pal and Grewal, 1975), while the addition of K in soil decreased the incidence of the PB disease regardless of the presence of N_2 and P in the soil. The age of the plant favours the susceptibility of the pathogen. The highest incidence of cent percent (100 %) was recorded in 15-day-old seedlings and the lowest incidence (25%) in 4-month-old plants (Mishra and Shukla., 1986).

Storage of pathogen:

It is quite challenging to store and maintain the virulence of the fungus *P. cajani* causing Phytophthora stem blight in pigeon pea. Mainly, the pathogen isolates are kept on tomato juice agar slant or broth (7 to10 day-old- culture) for short-term storage at 15°C in a dark incubator. The cultures are revived and transferred to a new slant every 2 to 4 weeks to maintain their vigour potential. While, in the case of long-term storage (6 to 8 months), the culture's slant is stored in distilled water. Another economical way to store culture is to cut 8 to 10 small pieces from an actively growing culture and place them in small tightly closed bottles containing autoclaved distilled water and keep them at room temperature in the dark

Disease Management:

1. Planting of healthy or pathogen-free seed.
2. Adaptation of wider intercropping space.
3. Follow the crop rotation with non-host crops such as cereals.
4. Destruction of the infected pigeon pea stubble and alternative host species *viz; Atylosia* spp. and wild *Cajanus* spp. reduced the amount of inoculum.

5. Phosphorus acid is known to effectively control various oomycetes diseases as phosphoric acid moves upward and downward through xylem and phloem in plants.
6. Proper field sanitation and drainage should be done and low-lying areas for sowing should be avoided, these practices reduce the disease incidence since, water-logging may predispose the crop to Phytophthora blight under congenial conditions (Singh and Chauhan., 1985).
7. Always prepared raised seedbed with proper and good drainage facilities.
8. Sowing time should be managed such that it doesn't coincide with heavy rainfalls
9. Resistant varieties like ICPL 12055, ICPL 12114, JKM - 189, and JA - 4 should be grown.
10. Seed treatment with Metalaxyl 35% WS @ 3gram/kg seeds and also spray of Metalaxyl @ 500g per hectare is recommended.
11. Fungicide Brestan-60 control PB in the 1-month-old plant when applied before inoculation with Pdc pathogen under pot condition.
12. Incidence of PB reduced with the spray or soil drenching with two phytoalexins Phytoalexin- 84_ and Induce (Sheila and Nene., 1987).
13. Application of *Trichoderma viride* 1% WP@ 8 g/Kg seed as seed treatment and @ 200 g/acre for soil treatment reduces the incidence of the disease.
14. Direct application of slow releasing of phosphorous acid formulations (curdlan or pestan) using a carrier coated with polysaccharides resulted in excellent control of PB disease (Park et al., 2007).
15. Application of *Trichoderma viride* 1% WP@ 8 g/kg seed as seed treatment and @ 200 g/acre for soil treatment reduces the incidence of the disease.

Conclusions:

The disease Phytophthora blight (*Phytophthora drechsleri* f. sp. *cajani*) is disputably one of the important yield boundaries of pigeon pea (*Cajanus cajan*), especially short-duration varieties. For eco-friendly and sustainable management of the disease, different antagonists, and resistant varieties were extensively tested as bioagents and they may be used with fungicides for effective management of PSB disease. Commercially available metalaxyl formulation – Ridomil MZ – is equally effective against *P. drechsleri* f. sp. *cajani*, and it may be used with *P. fluorescens* and *T. viride* for more effective and eco-friendly management of Phytophthora blight of pigeon pea. Furthermore, Ridomil MZ has a lower risk of cross-resistance with populations that are metalaxyl-resistant and have different modes of action. The chemical method of controlling PSB is not, however, cost-effective or environmentally friendly. Therefore, more focus is needed on the development of resistant varieties for sustainable management and higher productivity per unit area.

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About Editors

Dr. Parashurama T.R (M.Sc., PGDMP., Ph.D) is Founder Secretary of Panchavati Research Academy for Nature (PRANA), Kalamaji, Central Western Ghats, Shimoga and Former Principal of Kumadvathi First Grade College, Shikaripura. He received Bachelor science (2003), Mater of Science in Botany (2005) and Ph.D (2014) on Medicinal plant Pathology from Kuvempu University. His research interest includes medicinal plants, Ethno-botany, Pteridology, Phyto-chemistry and Plant Biodiversity. He was awarded JRF and SRF under DST, New Delhi sponsoring Project. He has published 34 research papers in National and International Journals and two book chapters in national edited volumes and also published 3 edited books. He has participated (36) in many National and international Seminars, Conferences and workshops with presented 11 papers. He contributed many significant new reports on medicinal plant diseases. He has excellent work experience in teaching, Administrative and research with various academic institutions and Universities.

Dr. Y. Linthoingambi Devi has finished her doctoral degree recently in Department of Genetics and Plant Breeding from College of Agriculture, IGKV, Raipur, Chhattisgarh. She did her M.Sc. from CPGAS, CAU, Barapani, Meghalaya. She had published 6 research papers, 11 popular articles, 1 edited book, 7 book chapters with few others in review and had attended a number of conferences, seminars, trainings, webinars etc. She had cleared ICAR-NET, CSIR NET, DBT-NET and UGC-NET in different subjects. She has achieved several awards like best young breeder award, best research scholar award, young scientist award, best oral and poster presentation and others. She is a recipient of National Fellowship for Schedule Caste students and also a member of Indian society of Genetics and Plant Breeding, Indian society of plant breeding, Agro-environmental Education & Farmers Welfare Society and ATDS Society lifetime member.

Mr. Asif Mohi Ud Din Rather is currently working as Research Scholar, at Division of Vegetable Science Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar Srinagar, India. He is MSc in Vegetable Science from SKUAST-Kashmir. He has Three years of experience in research and extension. He is recipient of Young Horticulturist Award-2021 from ATDS. In Addition to the number of publications in reputed journals, the author is actively involved as reviewer in many reputed publishing houses. His current area of research interest includes nanotechnology and development of nanofertilizers and evaluation.

Mr. Sachin Kumar Yadav is presently pursuing Ph.D. in Agriculture Entomology from Chandra Shekhar Azad University of Agriculture & Technology Kanpur, U.P. 208002. He has completed his B.Sc. in Agriculture (Hons.) from Kulbhaskar Ashram Post Graduate College, Prayagraj in 2018. He has obtained his Master's degree in Agriculture Zoology & Entomology from University of Allahabad, Prayagraj, being department topper and Gold Medalist in 2020. He has published several research papers in national & international peer reviewed reputed journals. He has participated in various contributed abstracts in several national and international seminar & conferences. He has also to his credit several articles and book chapters. He has received International Outstanding Entomologist Award.

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