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Seed treatments for sustainable agriculture-A review

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Abstract: Seed treatment refers to the application of certain agents physical, chemical or biological to the seed prior to sowing in order to suppress, control or repel pathogens, insects and other pests that attack seeds, seedlings or plants and it ranges from a basic dressing to coating and pelleting. Introduction and ban of arsenic (used from 1740 until 1808) is the key milestones in the history of modern seed treatment till then a continuous research and advancement in this technology is going on. The technological advancement prepared a roadmap for refining existing seed treatment technologies and future work on technologies like fluid drilling as a way to sow germinated seeds where gel can also serve as a delivery system for other materials, seed priming advances the early phase of germination without redicle emergence. Another advanced technology, solid matrix priming (SMP) has been evaluated as a means to advances the germination of seeds and serve as a carrier for useful material too. Physical and biological seed treatments alone an alternative to chemicals or in combination with a chemical treatment are being used worldwide because of their environmental safety and socioeconomic aspects. Biological seed treatments are expected to be one of the fastest growing seed treatment sectors in the near future, in part because they are easier to register at Environment Protection Agency (EPA). Lack of awareness to seed treatments at farmer's level is one of the limiting factors in disease management and hence, efforts should be made at farmer's level to adopt the technology. Keeping the all above facts in mind, selected seed treatment technologies with their improvement and significance will be discussed in this review.

Keywords: Biopriming, Fluid drilling, Pelleting, Seed coating, Seed treatment

INTRODUCTION

Seed is a basic and vital input for sustained growth in agricultural productivity and production since ninety percent of the food crops are grown from seed (Schwinn, 1994). The role of seed in agriculture sector is of prime importance in developing countries like India where the population and GDP (Gross Domestic Product) considerably depend on agriculture sector (Tyagi, 2012). The seed-borne and early season diseases and insects create devastating consequences if not managed timely. Emphasis on present day agriculture is to produce more with lesser land, water and manpower. The age old environmental friendly disease management practice like sanitation, crop rotation, mixed cropping, adjustment of date of sowing, fallowing, summer ploughing, green manuring composting etc. (Sanjeev Kumar, 2012) to combat plant pathogens have already lost their acceptability and are being reevaluated as a component of integrated pest management (Reddy, 2013). The chemical control via soil/foliar application has its limitation such as high cost, selectivity, affect on target organisms, development of pest resistance, resurgence of pests, pollution of food and feed, health hazards, toxicity towards plants and animals, environmental pollution etc (Rahman *et al*., 2008). The pace of development and durability of resistant varieties had been slow and unreliable in spite of tremendous advancement made in the field of plant genetic engineering (Reddy, 2013).

Considering these limitations with a growing world population, there has been a growing interest to develop such management practices/tools which alone or in combination with other practices could bring about a reasonably good degree of reduction of inoculum potential and at the same time ensure the sustainability of the production, cost effectiveness and healthy ecosystem and 'seed treatment' is one of these tools (Sanjeev Kumar, 2012). Seed treatment like baby care being with the mother (Heydecker and Coolbear, 1977) and it ranges from a basic dressing to coating and pelleting (ASF, 2010; Krishna Dubey, 2011). Seed treatment refers to the exposure of the seeds to certain agents physical, chemical or biological which are not

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employed to make the seeds, pest or disease free only but treated to provide the possibility of pest and disease control also, when needed during germination and emergence of young plant and early growth of the plant (Forsberg *et al.*, 2003). Seed treatments have played and are still playing a pivotal role in sustainable crop production which is also evidenced from the history of mankind. Seed treatments have helped to improve the yields of many different crops by providing the protection from pre and post-emergent insects and diseases and insurance of a uniform stand across a wide variety of soil types, cultural practices and environmental conditions. Seed treatments provide an economical crop input that is applied directly on the seed using highly effective technology (Crop Life Foundation, 2013). Moreover, other crop protection techniques are now being replaced with seed treatments by virtue of their residual systemic efficacy (Schwinn, 1994). From time to time different techniques have been proposed for applying and more advanced techniques are required which give more control of plant diseases by affecting seed health least (Gaudet and Puxhalski, 1992 and Nameth, 1998).

Seed treatment has some advantages over other pest control or crop enhancement measures such as (DPPQS, 2007):

- More alternatives available to chemical in effective manner.
- Protection of seed during storage and after planting in soil.
- Reduction in initial inoculum.
- Minimize the environmental side effects viz. reduce risk to non target organism, no problem of drift and reduction in land surface exposed to active ingredients with maximum efficacy reduce the rate of application per hectare, thus decrease the cost of disease control per ha while achieving exceptional control of seed borne, soil borne and foliar diseases.
- Increase seed vigour which is the key of successful field emergence and establishment.
- Even and uniform application of the chemical.
- Combination of treatment can be applied more precisely.
- Breaking of seed dormancy and improve emergence and plant stand.

Some of the biggest success stories in plant disease control involve the use of seed treatment fungicides, particularly of small grain cereals, e.g., wheat, barley, and oats. They generally are less toxic to plant and animal life, eco friendly as applied at significantly reduced application rate. Another major impact that seed treatments have had on the small grain industry is their effect on plant breeding. In the early part of the 20th Century, many wheat breeders spent a considerable portion of their effort on breeding for resistance to common bunt. Today, with this disease controllable with seed treatment they are able to spend their efforts on breeding for other attributes, i.e. grain quality (Mathre *et al.*, 2001).

In this way seed treatment will play an important role in protecting the seeds and seedlings from seed borne diseases and insect pests affecting crop emergence and its growth. Commercial seed treatment to deliver pesticides has been extensively used for a wide range of crops and use of chemicals seed treatment will undoubtedly continue. Physical seed treatment (dry or aerated heat, hot water, radiation etc.) and methods using natural crop protection agents/microbial inoculants could be an alternative to chemical seed treatment methods in crop production. Research efforts in alternatives methods to chemical crop protection are currently being addressed worldwide especially with regards to food safety and environmental sustainability (Nicholas and Groot, 2013). Moreover, pre-sowing physiological treatments (seed priming, fluid drilling etc.) for seed enhancement have a pivotal role in seed treatment technology. Biological seed treatments are made up of renewable resources and contain naturally occurring active ingredients targeting protection against soil-borne pathogens, alleviate abiotic stress and increase plant growth (Schwinn, 1994). Keeping in view of the importance of seed treatment to achieve better crop stand of major crops, virtue of its IPM compatibility and the fact that many farmers in developing country like India not aware/do not adopt this practice, adoption of this practice by the farmers across the country, requires effective extension strategies to make them aware about different aspects of seed treatment and using treated seeds to enhance production and attaining food security as well. Moreover, the purpose of this review is to describe selected seed treatment technologies and their technological advancement that have helped out or will in the near future, the development of better and more uniform crop production.

Present scenario: The high cost of GM seed is a key factor in the high demand for and growth of chemical seed treatments. With the regulatory issues facing both granular and fumigant nematicides, there has been a great deal of focus on seed treatment uses of nematicidal and nematistatic products. A critical success factor for the seed treatment market was the development of a complete protection solution against various plant stressors in a single product that is grower-friendly, crop-friendly and environmentally responsible (Schwinn, 1994). Seed treatments, compared to conventional crop protection products, offer competitive costs, reduced application efforts and save the time. As a result, seed treatment is currently the fastest growing agricultural chemicals sector and has a significant economic impact on markets, particularly in the U.S. and Europe (Research and Markets, 2013).

Presently, 70% requirement of seed is met from the farmer's own stock which goes for sowing without seed treatment. Even if seed is sourced from the private or public sector agencies, except hybrid seeds, large percentage of such seed is untreated (Upadhyaya, 2013). The estimates reveal that on an average, 80% of the seed sown in the country is untreated, as against the 100% seed treatment practice in developed countries. Seed treatment not only protects the seeds from seed and soil borne diseases but also gives protection to the emerged seedlings from sucking insect pests affecting crop emergence and its early growth. However, many farmers in the country are neither familiar with the practice nor follow it (DPPQS, 2007).

Present and ongoing seed treatment worldwide:

- The seed treatment product VOTiVO™, (*Bacillus firmus*) from Bayer Crop Science is used in an increasing number of countries to reduce the impact of nematodes and company has recently launched its new nematicide based on the active ingredient fluopyram, marketed under the brand names Velum™ and Verango™ in 2014 (Bayer Crop Science, 2014). Company has submitted a US EPA registration application for ILeVO, the first seed treatment to manage soybean sudden death syndrome (Crop Protection Monthly, 2014).
- Baden Aniline and Soda Factory (BASF) company has developed a triple-action fungicide seed treatment for corn. Nufarm America is bringing a full portfolio of seed treatments to the market and 15 products have been available by the end of 2010. In 2013, BASF has filed a legal action with the General Court of the European Union challenging the Commission's decision to restrict major seed treatment uses of the insecticide fipronil (Crop Protection Monthly, 2014).
- Syngenta's 'Cruiser Maxx Potato Extreme' seed treatment has been registered for use on potato crops in Canada and company is to have a new seed treatment product for controlling soybean cyst nematodes in 2014. In 2013, Syngenta has officially launched *Clariva*, a proprietary seed treatment nematicide based on the Pasteuria technology (Crop Protection Monthly, 2014).
- Syngenta has introduced the first seed treatment (FarMore® F300 cucurbit, FarMore® FI400) insecticide for small seeded vegetables. The insecticide is a component of the FarMore® Technology which delivers broad spectrum insect and disease protection for young vegetable crops against a range of important pests (Syngenta, Seedcare, 2012). In total Syngenta invests more than USD 2 million a day to discover and deliver innovative technologies (Syngenta, Research and Development, 2009).
- Certis Europe has signed an agreement with Chemtura AgroSolutions that extends its distribution of seed treatment products (Crop Protection Monthly, 2014).

However, seed treatments should not be considered as a cure for all maladies for the selection of poor/ unhealthy seed lots. For example, treatment of seeds with excessive mechanical damage or other damages or seeds kept in poor storage conditions, or genetic differences in a variety will not increase seed germination. Seed treatment is an important approach has been employed since the middle of the 17th century when brining was used by farmers in the United Kingdom to control Bunt of wheat (Maude, 1996). Introduction of new modern fungicides and insecticides in 1990s gave more and wide opportunities for advancement of seed treatment technologies.

Seed treatment chronology (FIS, 1999**)**

Year	Event
Approx. 2000 B.C. to 100 A.C	First soaking technique, use of sap of onion cypress (Egypt, Greece, Roman Empire)
Middle Ages	Soaking in chlorine salt and manure
1600's	Soaking in salt water
Mid 1700's	Introduction of copper salt
1740's	Introduction of arsenic
1765	Soaking in hot water (Germany)
1808	Ban of arsenic
1915	Introduction of organo-mercurics
1960's	Introduction of first systemic fungicide
1970's	First systemic fungicide against air borne pathogen
1982	Ban of organo-mercurics in Western Europe
1990's	Introduction of new modern fungicides and insecticides

Diseases and insect pests commonly associated with seed: When we plant a seed in the ground microorganisms (fungi, bacteria, virus etc.) and soil insects tend to exploit it as a food source. Some of these microbes/insects can injure the seed or plant by causing disease and economic damage to plant stands and the plant in general **(**Taylor and Harman, 1990**)**.

Diseases and associated pathogens: The most common organisms usually associated with plant diseases are *Pythium* species, *Fusarium*, *Diploida*, *Penicillium*, *Helminthosporium*, *Ustilago* (smuts), *Rhizoctonia* etc. (Agrios, 2005) and the diseases commonly associated with above microorganisms (TeKrony, Dennis M., 1976) are:

- Seed rot-rotting of seed before germination.
- Damping-off and seedling blight-soft rot of stem tissues near ground level and water soaking of seedling tissues.
- Seedling wilt-gray coloration starting at the leaf tips and extending rapidly to the whole leaf, causing complete collapse of seedlings in 24 to 48 hours.
- Root rot-water soaking, browning and sloughing of

Table 1. Chemical compounds currently used as small grain cereal seed treatments (Mathre *et al*., 2001).

Common name	Chemical name	Trade name
Captan	N-trichloromethylthio-4-cyclohexene-1,2-dicarboximide	Agrosol, Agrox, Granox, Orthocide
Carboxin	5,6-dihydro-2-methyl-N-phenyl-1,4-oxathiin-3-carboxamide	Vitavax
Difenoconazole	cis,trans-3-chloro-4-[4-methyl-2-(1H-1,2,4-triazol-1-ulmethyl)-1,3-dioxolan-2-yl]phenyl 4-chlorophenyl ether	Dividend
Imazalil	(+)-allyl 1-(2,4-dichlorophenyl)-2-imidazol-1-ylethyl ether	FloPro IMZ, Double R, Deccozil, Nu-Zone, Fungaflor
Mancozeb	Zinc Manganese ethylenebisdithiocarbamate	Dithane M-45, Mankocide, Mansul, Penncozeb
Maneb	Manganese ethylenebisdithiocarbamate	DB Green, Granol NM, Trinox, Pro-Tex
Metalaxyl	methyl N-(2-methoxyacetyl)-N-(2,6-xylyl)-DL-alaninate	Apron, Allegiance
PCNB	Pentachloronitrobenzene	Terrachlor, Parflo, Terra-flo, Terrazan
Tebuconazole	(RS)-1-(4-chlorophenyl)4,4-dimethyl-3-(1H-1,2,4-triazol-1-ulmethyl) pentan-3-ol	Raxil, Preventol, Tebuject
Thiabendazole	2-(4-Thiazolyl)-benzimidazole	TBZ, Mertect, Metasol
Thiram	Tetramethylthiuramdisulfide	Arasan, Vertagard, Thiramad
Triadimenol	(1RS, 2RS; 1RS, 2SR)-1-(r-chlorophenoxy)-3,3-dimethyl-1-(1H-1,2,4-triazol-1-yl) butan-2-ol	Baytan
Triticonazole	(+)-(E)-5-(4-chlorobenzylidene)-2-dimethyl-1-(1H-1,2,4-triazol-1-ylmethyl) cyclopentanol	Charter

rootlets.

- Loose and covered smut of small grains.

Cereal grain insects: The insects commonly associated with cereal grains (TeKrony, Dennis M., 1976) are:

- Rice Weevil-found in all grains, this pest is the most common and most destructive of the stored grain insects.
- Granary Weevil-this insect is very similar to the rice weevil and can only be distinguished from it by microscopic examination. It cannot fly.
- Saw-toothed Grain Beetle-this is a reddish-brown to black insect which has 6 saw-toothed projections on each side of the front part of the body, visible under microscope.
- Indian-meal Moth-this moth has wings that have a reddish-brown, coppery luster on the outer two-thirds, with the rest light gray. The larvae may completely web over the surface of the infested grain.

There are some chemical compounds enlisted in Table 1 currently used as small grain cereal seed treatments (Mathre *et al*., 2001)

Category of seed treatment: Seed treatments vary depending on type of seeds which are treated and can be categorized **(**Taylor and Harman, 1990**)** as:

Category 1: It is done for those seeds which are extremely expensive (>500 $/kg) and produced in small quantities such as hybrid flower seeds. These are rarely treated because the risk to damage the seed exceeds expected gain.

Category 2: In this category those seeds are treated which are moderately expensive (100 to 500 $/kg) and produced in moderate quantities and this category seed treatment is preferred by relatively expensive equipment and materials because maximum performance potential is required. Small seeded vegetable crops are come in this category.

Category 3: This type of seed treatment is frequently done for those seeds which are produced in large quantities and are relatively low in price value (1 to 5 $/kg). Most of agronomic seeds are come in this category.

METHODS OF SEED TREATMENT

At our present status of technological progress it is much more likely new than ever before that economically advantageous seed treatment technique can be found. Seed treatment complexity ranges from a basic dressing to coating and pelleting (ASF, 2010; Krishna Dubey, 2011). Although, seed treatment like baby care begins with the mother (Heydecker and Coolbear, 1977), the treatment with which we are mainly concerned in this article are those applied to the seeds themselves at the stage almost immediately before sowing for control of plant diseases transmitted through seeds. The different seed treatments are as follows:

Physical seed treatment–an alternative to chemicals: Considering the side effects of chemicals on ecosystem and organism, some alternative methods were evolved and are being used presently for treating seeds (Jindal *et al*., 1991; Elwakil, 2003; Aladjadjiyan,

Table 2. Hot water treatment for some seed borne pathogens (Flyod, 2005).

Crop/disease	Pathogen	Treatment
Brassica canker	*Leptosphaeria maculans*	30 min at 50^0 C
Brassica leaf spot	*Alternaria brassicae*	20 min at 50^0 C
Brassica leaf spot	*Alternaria brassicicola*	18 min at 50^0 C
Brassica black rot	*Xanthomonas campestris pv. campestris*	30 min at50^0 C
Cereal loose smut	*Ustilago segatum var. tritici*	5 h at 21^0 C presoak + 1 min at 49^0 C + 11 min at 52^0 C
Millet downy mildew	*Sclerospora graminicola*	10 min at 55^0 C
Rice blast	*Magnaporte grisea*	6-12 h in cool water + 1-2 min at 50^0 c
Rice leaf spot	*Helminthosporium oryzae*	7 min at 51^0 C
Moongbean black rot	*Xanthomonas campestris pv. phaseoli*	20 min at 52^0 C
Tomato canker	*Clavibacter michigansis ssp. michigansis*	60 min at 53^0 C
Pea blight	*Pseudomonas syringae pv pisi*	15 min at 55-60^0 C

2007). In the case of agrochemicals, they are less suitable to be used as it degrades land, environment, and therefore the human and animal food (Chapman and Harris, 1981; Vasilevski, 2003). Thus, it is important to investigate the use of sustainable methods, such as physical methods in this century (Amein *et al.*, 2011). New technologies to apply them have come which make them economically viable (Taylor and Harman, 1990; Rahman, *et al*., 2008; Nicholas and Steven, 2013).

Hot water treatment: Hot water treatment is a very age old practice to control many seed-borne diseases by using temperatures hot enough to kill the organism but not quite hot enough to kill the seed and it is still being used as a very effective alternative (Floyd, 2005; Muniz, 2001). This method of treating seed continue to be a standard method of pathogen elimination which is more eco friendly and effective compared to chemical treatments, however they can cause the loss of seed viability (Catalan and Edgardo, 1991; Erdey *et al.*, 1997; Nan *et al.*, 1998; Meah, 2004). Treatment for the fungal disease blackleg and the bacterial disease black rot of crucifers is a classic example of hot water treatment (Walker, 1923; Napoles *et al*., 1991). Before giving the hot water treatment pre-warm loose seed in porous bag, such as cheese cloth for 10 minutes at 20^0C water. The amount of seed should be just sufficient to allow thorough and immediate wetting. Place pre-warmed seed in water bath that will hold the recommended temperature. Length of treatment must be 'exact'. It must be carefully and accurately done. A few degrees cooler or hotter than recommended may not control the disease or may kill the seed. After treatment, dip bags in cold water to stop heating action. Once seeds have cooled, spread them thinly on a paper towel to allow drying (Jindal *et al*., 1991). Recommends applying protective seed treatment fungicide to hot-water treated seed and thiram is most frequently suggested seed-protectant fungicide (do not use treated seed for food or feed). Plant the seed as soon as it is thoroughly dry. Do not store treated seed (Floyd, 2005; DTTTI-RADA, 2012). Suggested for eggplant, pepper, tomato, cucumber, carrot, spinach, lettuce, celery, cabbage, turnip, radish, and other crucifers. Hot water treatment can be damaging or not practical for seeds of peas, beans, cucumbers, lettuce, sweet corn, beets and some other crops (Nega *et al*. 2003; Floyd, 2005; Miller and Lewis Ivey, 2005). Some hybrid varieties of cauliflower may be damaged by the recommended treatment. Old seed may be severely damaged by this treatment and hence a small sample of any seed lot over one year old should be treated first followed by tested for germination to determine amount of injury that may occur. Seeds that can be treated by hot water are listed in the Table 2 (Floyd, 2005).

Dry heat treatment: Thermal seed treatment has been practically applied in different ways. A simple way of thermal treatment is solarization, where the seeds are heated by irradiation from the sun (Luthra, 1953 and Luthra and Sattar, 1934), which is sometimes applied in warm countries, but is of little interest in industrial agriculture due to low precision and difficulties with large-scale application. Dry hot air has been developed for use against insects in grain stocks (Dermott and Evans, 1978; Evans *et al.*, 1983; Thorpe *et al.*, 1983 and Thorpe, 1987) and is applied in Australia at capacities up to 150 tons/hour (Banks, 1998), but in most cases it has not shown good potential against fungal infections in seeds (Couture and Sutton, 1980). Dry heat treatment (DHT), a powerful and agrochemical-free means of inactivating seed-borne virus and other pathogens, has been extensively used for value-added vegetable seeds in Korea, Japan, and some other countries (Seung-Hee Lee *et al.*, 2004). Thomas and Adcock (2004) reported dry heat treatment for a period of 4-7 days at 65^0 C or up to 4 days at 70^0 C reduce, possible eradicate anthracnose infection in lupine seeds.

Aerated heat treatment: In the late 19th century, various hot water and hot humid air treatments were found to decontaminate seed from seed-borne pathogens (Jensen, 1888). The hot water treatment method was used by seed companies since the early 20th century (Johnsson, 1990 and Neergaard, 1977). It had, however, important disadvantages, such as high

Table 3. Recommended seed treatment for different crops (TNAU Agritech Portal, 2014).

S. No.	Name of Crop	Pest/Disease	Seed treatment	Remarks
1.	Sugarcane	Root rot, wilt	Carbendazim (0.1%) 2 gm/kg seed *Trichoderma* spp. 4-6 gm/kg. seed	For seed dressing metal seed dresser/ earthern pots or poly-thene bags are used.
2.	Rice	Root rot disease other insects/pests Bacterial shealth blight	*Trichoderma* 5-10 gm/kg. seed (before trans-planting) *Chloropyriphos* 3gm/kg seed. *Pseudomonas flourescens* 0.5% W.P. 10 gm/kg.	-do-
3.	Chillies	Anthracnose spp. Damping off	Seed treatment with *Trichoderma viride* 4g/kg, Carbandazim @ 1g/100 gm seed.	-do-
4.		Soil borne infec-tion of fungal dis-ease Jassid, aphid, thrips	*Trichoderma viride* @ 2 gm/kg. seed and *Pseudomonas flourescens*, @10gm/ kg. Captan 75 WS @ 1.5 to 2.5 gm a.i./litre for soil drenching. *Imidacloprid* 70 WS @ 10-15 gm a.i./kg seed	-do-
5.	Pigeon pea	Wilt, Blight and Root rot	*Trichoderma* spp. @ 4 gm/kg. seed	For seed dressing metal seed dresser/ earthern pots or poly-thene bags are used.
6.	Pea	Root rot White rot	Seed treatment with *Bacillus subtilis* *Pseudomonas fluorescens* Soil application @ 2.5 – 5 kg in 100kg FYM or *Carbendazim* or *Captan* 2 gm/kg. seed *Thiram*+*Carbendazim* 2gm/kg seed *Carbendazim* or *Captan* 2gm/kg seed	-do-
7.	Bhendi	Root knot nema-tode	*Paecilomyces lilacinus* and *Pseudomo-nas fluorescens* @ 10 gm/kg as seed dresser.	-do-
8.	Tomato	Soil borne infec-tion of fungal disease Early blight Damping off Wilt	*T. viride* @ 2 gm/100gm seed. Captan 75 WS @ 1.5 to 2.0 gm a.i./litre for soil drenching. *Pseudomonas fluorescens* and *V. clamy-dosporium* @ 10gm/kg as seed dresser.	For seed dressing metal seed dresser/ earthern pots or poly-thene bags are used.
9.	Coriander	Wilt	*Trichoderma viride* @ 4 gm./kg seed.	-do-
10.	Brinjal	Bacterial wilt	*Pseudomonas fluorescens* @ 10gm/kg.	-do-
11.	Leguminous Vegetables	Soil borne infec-tion Nematode	*Trichoderma viride* @ 2 gm/100gms. seed. Carbofuran/Carbosulfan 3% (w/w)	-do-
12.	Sunflower	Seed rot Jassids, Whitefly	*Trichoderma viride* @ 6 gm/kg seed. *Imidaclorprid* 48FS @ 5-9 gm a.i. per kg. seed *Imidacloprid* 70WS @ 7 gm a.i. per kg. seed	-do-
13.	Wheat	Termite Bunt/False smut/ loose smut/ covered smut	Teat the seed before sowing with any one of the following insecticides. i) Chlorpyriphos @ 4 ml/kg seed or Endosul-fan @ 7ml / kg seeds Thiram 75% WP Carboxin 75 % WP Tebuconazole 2 DS @ 1.5 to 1.87 gm a.i. per kg seed. *T. viride* 1.15 % WP @ 4 gm/kg.	

Contd..…….

14.	Cruciferous vegetables (Cabbage, Cauliflower, Broccoli, Knol-khol, radish)	Soil / Seed borne diseases (Damping off) Root knot nematode	Seed treatment with *Trichoderma viridi* @ 2 g / 100 g seeds Captan 75% WS @ 1.5 to 2.5 gm a.i./litre for soil drenching. *Pseudomonas fluorescens* and *Verlicillium clamydosporium* @ 10gm/kg seed as seed dresser	-do-
15.	Gram	Wilt and damping off	Seed treatment with *Trichoderma viridi 1% WP @ 9 gm/kg seeds* Combination of Carbendazim with carbosulfan @ 0.2% Carbendazim with Thiram with carbosulfan @ 0.2% Treat the seed with *Chlorpyriphos* 20 EC @ 15-30 ml a.i./kg seed.	
16.	Potato	Soil and Tuber borne diseases	Seed treatment with MEMC 3% WS @ 0.25% or boric acid 3% for 20 minuts before storage.	
17.	Barley	Loos smut Covered smut Leaf stripe Termite	Carboxin 75% WP Thiram 75% WP @ 1.5 to 1.87 gm a.i./kg seed. Treat the seed with *Chlorpyriphos* @ 4 ml/kg seed.	
18.	Capsicum	Root knot nematode	*Pseudomonas fluorescens 1% WP, Paecilomyces lilacirius* and *Verticillium chlamydosporium* 1% WP @ 10g/kg as seed dresser.	

treatment cost and low precision often resulting in incomplete treatment effect or reduced germinability and it was therefore almost completely abandoned for cereals after the 1960's when cheap and efficient chemicals had became accessible. Hot, humid, air, or "aerated steam", treatment has been proposed as a way of avoiding the problems inherent in hot water treatment (Tapke, 1926; Miller and McWhorter, 1948; Baker, 1969; Kobayashi, 1990) and as applied in a fluidized bed it has shown potential for large-scale seed sanitization in practice (Forsberg *et al.*, 2002). Basically, the thermal treatment method used consists of two phases: The heating phase, where the seeds are heated for a certain time with air having a certain temperature and relative humidity calculated for good disinfestation, followed by a cooling phase that interrupts the treatment process before seeds are injured. The devices were constructed to permit precise control of important parameters (temperature, air humidity, treatment time, air flow and treatment and cooling durations). According to Weimer (1952) anthracnose seed infection in lupin was reduced by 80% after hot air treatment for 7 h at 70^0 C and eradicated after a similar period at 75^0 C. Successful pathogen control achieved by Forsberg *et al.* (2005) aerated heat treatment seed treatment against combined infections of *S. nodorum* and *Fusarium* spp, and for *T. caries* on wheat, infections of *D. teres*, and *B. sorokiniana* on barley and infections of *D. avenae* and *U. avenae* on oat.

Commercial applications using aerated steam have been developed for treatment of lobelia seeds against *Alternaria* infection (Hall and Taylor, 1983 and Mebalds *et al.,* 1996), and for treatment of sugarcane stalks against ratoon stunting disease and other sett-borne infections (Cochran, 1976; Srivastava *et al.*, 1977; Cochran *et al.,* 1975, 1978; Damann, 1983; Edison and Ramakrishnan, 1972; Singh *et al.*, 1980; Viswanathan, 2001).

Radiation treatment: Seed treatment with chemical pesticides has different unwanted effects especially the persistence of the toxic principles in the plant system and the environment. Radioactive irradiation has also in a few cases been reported to be successful (Cuero *et al*., 1986; Bagegni *et al*., 1990), but has not been widely used because exposures sufficient to control pathogens often also kill the seeds. Different types of electromagnetic radiation such as gamma ray (Harwalkar *et al*., 1995), high energy electrons (Sitton *et al.,* 1995), ultrasonic radiation (Nagy *et al*., 1995), microwave (Stephenson, *et al.*, 1996; Anna Aladjadjiyan, 2010) and UV radiation (Gupta and Chaturvedi, 1987; Bhaskara Reddy *et al*., 1995,1998; Therdetskaya and Levashenko, 1996) have been used as alternative seed treatment agents for management of microbial infestations. Inactivation or control of microorganisms and insect pests by gamma irradiation on various plant products have been reported (Rao *et al.,* 1994 and Sinha *et al*., 1994). Singh and Singh (2005) reported gamma irradiation at non-injurious levels (0.10- 0.50 kiloGray) reduces microbial infestation in seeds of all the four rice cultivar tested and highest rate of seed germination was recorded among the seeds irradiated with 0.10 kiloGray (kGy) while root growth was stimulated by low doses of gamma ray. Laser light has many applications in agriculture, but there is still much work to provide scientific evidence of its potential use as an alternative for the control of diseases originating in the seed, especially for fungi that are internal. Even laser treatment has been reported to be effective (Bel'skii and Mazulenko, 1984), although since laser beams are narrow and the whole surface of the seed should be evenly exposed for good effect it is of limited practical interest. Hernández Aguilar Claudia *et al*. (2011) recently reported that low intensity laser irradiation could be an alternative method to control seed transmitted diseases in maize seed. The main innovation of the developed technology by Dr. Golota Vladimir Ivanovich is the use of 'ozone technology' for pre sowing seed treatment. It allows in the environmentally friendly way to carry out the activation for seed and as consequence the increase in the crop capacity up 10-15%. (Ivanovich, 2011).

Chemical and biological seed treatment: Now a day's chemical seed treatment is very common and worldwide practiced due to its wide spectrum ability to control plant diseases and pests taking less time and a number of automatic treatment machineries with high level of accuracy are available which makes it less labor intensive work (Nameth, 1998). Chemical seed treatments are fungicides or insecticides, applied to seed, to control diseases of seeds and seedlings; insecticides are used to control insect pests. Some seed treatment products are sold as combinations of fungicide and insecticide. Typically, chemical seed treatments do not offer benefits associated with root development, drought proofing or crop yield (EcoChem, 1998).

Treatment of seed with beneficial micro-organisms including fungi and bacteria (species of *Trichoderma*, *Pseudomonas*, *Bacillus*, *Rhizobia* etc.) ameliorates a wide variety of biotic, abiotic, and physiological stresses to seed and seedlings (Mastouri *et al*., 2010). Inoculation of seeds with such biological agents in combination with priming (Biopriming) potentially able to promote rapid and more uniform seed germination and plants growth (Moeinzadeh *et al*., 2010) and in several cases, has been reported to enhance and stabilize the efficacy of biological agents (Callan *et al*., 1990, 1991, Harman *et al*., 1989 and Warren and Bennett, 1999).

Seed treatment using emersion techniques: Seed emersion methods are those where seeds are steeped for varying periods of time in aqueous or solvent based liquids at ambient or raised temperatures with or without the addition of chemicals to eradicate seed borne organism (Black and Bewley, 2000; Martin and Woodcock, 1983; Rajesh Kumar *et al*., 2012).

(i) Seed soak in aqueous fungicides: Conventional fungicide seed treatments, such as aqueous suspensions and powders, have been used to improve germination and seedling vigor. The treatment of seeds by steeping them in aqueous chemicals to control pests and diseases is of ancient origin**.** The 17th century practice of brining and the use of seed steeps in inorganic and organic fungicides to control seed borne pathogens have been mentioned (Martin and Woodcock, 1983). The principle underlying such technique is that immersion of seeds in aqueous solutions or suspensions of pesticides result in partial or full hydration of host and pathogen tissue making both more susceptible to the penetration of chemical than they would have been in the dry state.

Reasons of decline the use of technique: Such penetration was necessary if deep seated pathogens were to be eliminated. This approach to seed treatment was particularly relevant during the era before the systemic fungicides become available for commercial use (Hung, *et al.*, 1992).

Advantages

- It is a non selective treatment for controlling any seed borne fungi and in addition giving protection against some soil borne pathogens (Singh *et al*., 2000).
- A patch treatment where upto 50 kg seeds can be treated at a time, compare with smaller amounts (upto 5 kg) using the hot water treatment.

Disadvantages

- It is not effective against bacteria.
- After 24 hrs of soaking seeds need to be dried for 6-12 hrs which is very labor intensive job and the rate of control is dependent on prevailing temperature during treatment.

Recent advances

- More recently a modified form of thiram soak treatment (0.2% thiram for 12 hrs at 25^0 C) has developed for the control of *P. betal* in monogerm sugar beet and this modification has been incorporated into the pelleting process for that crop in the UK (Payne and Williams, 1990). The aim of thiram soaking was to achieve penetration of seed tissue to eradicate internal pathogens. Expect for the UK uses specified above, this treatment has been superseded by the advent of systemic chemicals which have greater inherent mobility of action and when applied to the surface of seeds can penetrate their tissue to achieve the same effect (Hung *et al.*, 1992).
- More advanced technique is the organic solvent infusion technique (OSIT) to improve infusion of fungicides via organic solvents (O'Neill *et al*., 1979 and Papavizas and Lewis, 1976). Organic solvents are non-polar, easily penetrate the seed coat, carrying non-polar chemicals including many fungicides with them which volatilize quickly, leaving the fungicide deeper inside the seed and distributed more evenly than that obtained with conventional treatments (Meyer and Mayer, 1971). The amount of fungicide used by the infusion method is less than that required in a conventional seed treatment (Persson, 1988; Tao *et al*., 1974).

(ii) Use of antibiotics

The main purpose of immersion seeds in antibiotics has been to control seed borne bacteria. Antibiotics applied to the surface of seed have not been sufficiently penetrative to be effective against bacteria mainly located within the seed coat tissue. As a result seeds infected with bacteria have been immersed in aqueous solutions/suspensions of antibiotics or in water at high temperatures with or without the addition of various chemicals to kill or neutralize the pathogen

(Kannaiyan and Prasad, 1979; Vlakhov *et al.*, 1974).

Disadvantages

Phytotoxicity is a major problem of seed soak in antibiotics particularly with the use of streptomycin and it commonly results in b**l**eaching of cotyledons and stunting of seedlings.

(iii) Seed soak in inorganic chemicals

Pre sowing seed treatment where seeds are soaked in water, mineral solutions *viz.*, $CaCl_2$, $ZnSO_4$, cobalt sulphate/chloride, K_2SO_4, KH_2O_4, $CuSO_4$, sodium molybdate, boric acid, manganous sulphate and other (Mariappan *et al*., 2013) or growth regulators viz., ascorbic acid, kinetin, benzyl adenine, GA, CCC and other (Agboola, 2003 and Kumaran *et al*., 1993) alone or in combination found to speed up germination process, increased germination rate and seedling vigour, improved resistance to water and salinity stress and increased crop yields (Pandey and Sinha, 1995; Krishnaveni *et al*., 2010).

Limitations

- Many seed borne viruses are embryo located and treatments which inactivate them in the embryo may be phototoxic. Where, however the pathogen contaminate or is slightly invasive of seeds as is tomato mosaic virus, then remedial treatment are possible.
- Extraction of seeds in 20% hydrochloric acid for 30 minutes or with 10% or higher concentration of trisodium orthophosphate for 10 minutes inactivates the virus in many instances and these treatments can be used successfully when the virus is wholly superficial and are less effective when the virus has penetrated the seed coat.

Immersion techniques in future

- Seed immersion method now may have a decreased use for the treatment of fungi because of advent of systemic fungicides with less phytotoxicity but they remain important for the treatment of seed borne bacteria and to a lesser extent seed borne viruses.
- The advent of systemic fungicides, immersion methods loose impacts and the new technologies came in existence for application of pesticides homogeneously.
- Seeds are soaked in low concentrations of JA, typically for 24 hours, followed by drying. Other possible treatment options include the application of powders, dusting or application of slurries. After treatment the seeds can be stored and sown at a later stage. Plants grown from seeds treated with resistance inducing chemicals like salicylic acid, jasmonic acid etc. demonstrate long lasting effects on defense across the different developmental stages (Amein *et al*., 2011).
- The technology has been successfully demonstrated with seeds from tomato, sweet pepper, wheat and maize by Borcke (2007). In these tests, seeds were treated with JA in aqueous solutions for 24 hours. Typically seeds were planted eight weeks after treatment. Plants were challenged with a range of pests, caterpillars (of tobacco hornworm), aphids and spider mite for tomato, aphids for pepper and cucumber and Spooptera exempta caterpillars for maize and wheat. These pests were allowed to feed for between 2 and 14 days. In the experiments with caterpillars the leaf area consumed was reduced by between 40 to 60% in the plants grown from treated seeds compared with control plants. In the experiments with the spider mite, feeding was reduced and in addition reductions of pest population and in reproductive rates were observed.

Seed dressing: This is the most common method of seed treatment and seeds are dressed with modern pesticides in which chemicals may be applied as dry powder or in the form of slurry (Upadhyaya, 2013). Dressings can be applied at both farm and industries. Low cost earthen pots can be used for mixing pesticides with seed or seed can be spread on a polythene sheet and required quantity of chemical can be sprinkled on seed lot and mixed mechanically by the farmers. In villages, generally shovel is used for mixing the chemicals. However this often leads to uneven mixing and is not considered a standard method. The best way mix the chemical with seeds is to use motor or hand driven seed treatment drum. Before mixing seeds and chemicals seed materials must be weighed for applying the appropriate dose (Thippenswamy and Lokesh, 1997).

Seed coating: Seed coating require a special binder is used with a formulation to enhance adherence to the seed. Coating requires advanced treatment technology, by the industry (Arias-Rivas, 1994; Upadhyaya, 2013). The earliest methods of treating seed with fungicides were relatively crude. The first method used involved piling the seed to be treated on a solid surface and then dusting the top of the pile with the fungicide (Mathre *et al*., 2001; Taylor *et al*., 2008). It was then hand-mixed using a shovel until the grain appeared to be evenly coated. Later, a rotating drum was used to mix the seed with dust formulations of materials such as copper carbonate. This involved mounting a barrel at an angle, such that when it was turned by hand crank, the grain would tumble back and forth thus coating itself with the fungicide (Taylor *et al*., 1991; Taylor *et al*., 2004).

The first large seed treating machines were developed to handle the organic mercury fungicides that were available as liquids (Panogen) or dusts (Ceresan). One of these, the Panogen Treater, dripped the liquid fungicide into a large rotating container and the seed was coated as it tumbled through the treater. Another one, the Mist-O-Matic Treater, had a system whereby the liquid fungicide was dripped onto a whirling cone that caused the fungicide to become a “mist” which coated seed as it fell through this mist. Both of these treaters could handle hundreds of bushels of seed per hour so they were very efficient. Modern day treaters can handle even higher volumes of seed and operate by mixing the seed with slurry formulations of the fungicide (Mathre *et al.,* 2001).

For growers who want to treat smaller lots of seed on their farm, there are a number of End-Gate Treaters. These are treaters that mount on the back of the truck carrying the seed and drip the liquid slurry formulation onto the seed as it is elevated out of the truck with an auger. The tumbling action of the seed in the auger aids in the distribution of the treatment on the seed as it moves into the grain drill (Mathre *et al.,* 2001).

Now day's new technologies are being come for treating seeds with this method which have specially designed equipments taking full care about the safety about the person handling the treatment. In large scale treatment, automatic seed treatment plants such as Gustafson Treaters are used. In this machine facility of automatic calibration for both seed and chemical is available, and the technical person can use it without difficulty with the help of guidelines provided by manufacturer. Adhesive like Carboxy methyl cellulose, Dextrans, Gum arabic, Vegetable/Paraffin oil is used (Mathre *et al.,* 2001).

Limitations

- Care should be taken in selection of chemicals to be applied e.g. organomercurials are injurious to seeds, particularly to cracked seeds. Therefore they are used when disease incidence in the seed crop necessities it and in crops where seed is not easily injured e.g. rice, wheat, barley, cotton etc.
- Method is not of much use for treating maize, bean, peanut and vegetable seeds which may get injury during process and therefore it reduces seed vigour.
- Higher concentrations of chemicals are required.
- Doses are changed with seed moisture, seed size and duration of treatments, therefore it is very difficult to make recommendations.
- The seed coating did not improve germination and actually had a deleterious effect under dry conditions.

Recent advances

- A more recent development 'film coating' (Ester, 1994; Jyoti *et al*., 2003; Kim and Taylor, 2004). is being used in which active materials are dispersed or dissolved in liquid adhesive and applied to seeds either with a Fluidized Bed Treater (Bacon *et al*., 1988, or pharmaceutical coating drum (Taylor and Harman, 1990). Film coating has gained popularity as a seed-coating method over the last several years because of worker safety considerations. Film coating is often used on seed species that do not require pelleting (*Brassica* spp.) for precision planting but the seed requires some encapsulation due to plant protectant application (Hill, 1999).This technology permits the application of multiple coatings and the increase in seed weight ranges from 1-10%. Recovery rates have been reported as great as 90% and seed to seed variability is low (Taylor and Harman, 1990 and McQuilken *et al*., 1990).
- Polymeric coating has been investigated to retard imbibition rates when seeds are sown in wet soil. Imbibitional chilling injury in large seeded legumes and cotton have been attributed to rapid water up-take when seed of low moisture content are sown in a cold, wet soil (Herner, 1986) e.g. soybean, cotton, corn, seeds were coated with lanolin in acetone applied at 55^0 C. Water uptake is reduced and emergence was greater from coated than non coated seeds (Chachalis and Smith, 2001; Taylor and Kwiatkowski, 2001; Willenborg *et al*., 2004).
- Seed coating with peroxide compounds that provide oxygen to seeds have been studied under anoxic or near anoxic soil conditions. Beneficial results have been reported on rice seeds coated with CaO_2 and sown under flooded conditions (Leaver and Roberts, 1984).
- Macronutrients have been applied to seed in seed coating and reported to improve early plant growth. However, there are limitations to the quantity of fertilizer that can be applied effectively without injury to the seeds (Zeļonka *et al*., 2005; Farooq *et al*., 2012; Miraj *et al*., 2013).
- Beneficial microorganisms that may fix nitrogen enhance nutrient uptake can also be applied to seeds (Praveen *et al*., 2012; Nyoki and Ndakidem, 2014). Becker Underwood® company is the world's leader in research, development and production of yield enhancing microbial seed inoculants for legume which are scientifically proven to make more nitrogen available to legume crops and improve their yield potential e.g. Vault NP, Nodulator Liquid etc. (Backer Underwood, 2012).

Seed pelleting: The most sophisticated seed treatment technology, resulting in changing physical shape of a seed to enhance pelletibility and handling. Pelleting requires specialized application machinery and tech-niques and is the most expensive application (DPPQS, 2007). Because in seed coating chemical is in direct contact with seed thus the phytotoxic chemicals are not applied with this method and to overcome this drawback seed pelleting is a good alternative. Many crop seeds are small and irregular in shape which does not permit the accurate metering by mechanical planting equipments. The original purpose of pelleting was to increase the apparent seed size and weight to alter seed shape for precision planters. In addition to this, pelleting also provides the opportunity for greater loading of material around the seeds and the spatial orientation of active ingredient can be varied within the pellet (Halmer, 1988; Upadhyaya, 2013).

The general procedure is for seed mass, to roll or tumble while two components, a binder (adhesive) and inert filler are being added. The process is continued until the desired increase in seed volume is obtained. Seeds are dried after pelleting and can be stored.

Advantages

- Protect the seed against soaking injury in excess soil moisture but at the same time to facilitate the excess of soil moisture in conditions when this is sparse.
- Can carry any chemical in reasonably large quantity with no phytotoxic effect on seeds.

Limitations

- At progress in the technology of pelleting is not facilitated because the fact that manufactures keep their materials and processes a closely guarded secrets.

Recent advances

- Attempts have been made to incorporate not only insecticides and fungicides but also materials such as activated charcoal which guard the seeds to some extent against phytotoxic effects of pesticides applied to soil (Taylor and Warholic, 1987).
- The establishment of white clover seeds was enhanced by inoculation with root nodule bacteria combined with a lime based pelleting material (Lowther, 1974). The main intention of lime pelleting is to protect the rhizobia by counteracting mild soil or fertilizer acidity close to the seed. It also ensures better survival of the rhizobia when delays between pelleting and sowing are inevitable (NSW Department of Primary industries, 2005).
- Seed pelleting with nutrients is advancement in pelleting technology which enhances initial seed quality, field emergence, field potential and storability (Shrimathi *et al*., 2002).
- New encapsulation technology has been developed for the formation of capsules by gelation. Though the technology was developed for the delivery of somatic embryos, the procedure could be developed for natural seeds. The procedure for hydro gel encapsulation consist of mixing propagules with sodium alginate solution and then transferring the coated propagules to calcium salt that results in the formation of soft capsule (Redenbaugh *et al*., 1987; Domaradzki *et al*., 2012). Alginate capsules/pellets have been used to deliver *Trichoderma* and *Gliocladium* to soil for the control of damping off caused by *Rhizoctonia solani* (Lewis and Papavizas, 1987).

Permeation: Because in pelleting drying is must which is time consuming and labour intensive so that permeation is an alternative to this. In this practice dissolving of chemicals in organic solvents which can then carry them beneath the covering layers of seeds and which then evaporate so that permeation can be achieved without the need for drying the seeds since no water is used (Meyer and Meyer, 1971; Shao *et al*., 2007).

Limitations

- As far as is known at present, the chemicals do not penetrate the embryo but only into its vicinity, infect such penetration can be fatal.
- These above and other details await investigation and thus great care is needed, especially about duration of treatment.
- But if used carefully the permeation techniques to bring about a major technological advances in the field of seed treatment.

Successful of seed treatment

- *Phaseolus lunatus* seeds have been protected from the insect pest *Hylemia platuraby* infusing them with a 1 mM solution of Chloropyriphos.
- Microflora has been effectively eliminated from celery seeds by permeating them with ethylene oxide carried by Dichlorodifluoromethane (Anderson *et al.*, 1973).

Fluid drilling: The procedure of fluid drilling or gel seeding consists of germinating seeds in aerated water until redicle emergence. The seeds are then mixed in a viscous gel and sown with an appropriate drill (Gray, 1981). The gel facilitates sowing seeds without injury to the emerged redicle and maintains seed moisture.

Limitations

- This is an on farm operation and precedes the planting operation.
- Specialized planting equipments or modification of existing equipment was needed to sow germinated seeds.
- Additional cost to growers as well as the extra time, effort and equipment necessary to prepare the seeds.

Recent advances to exploit fluid drilling in plant diseases

- Gels have also been used to deliver pesticides and biocontrol agents for the control of soil borne diseases e.g. Metalaxyl and Captan were incorporated into a magnesium silicate gel to control damping off caused by *Pythium aphanidermatum* (Giammichele and Pill, 1984).
- Activated carbon can be incorporated into fluid drilling to detoxify herbicides in direct seeded lettuce (Taylor and Warholic, 1987).

Future of fluid drilling in pest management: Though the fluid drilling technique did not gain economical acceptance, interest continued for developing a pre-sowing seed treatment to enhance seedling establishment that would use existing planting equipments (Taylor and Harman, 1990).

Seed priming: Seed priming describes a broad group of hydration techniques employed to enhance seed performance in the field or in controlled environment production systems. The term, seed priming, is also used to describe the biological processes and changes that occur during seed hydration (and drying) treatments (Hacisalihoglu *et al*., 1999). Priming is of interest to seed researchers as a tool for understanding the germination process, and is of considerable interest to the seed industry as a vehicle for improved seed performance and quality. Seeds are primed (imbibed) to a water content and/or time period less than that required for complete germination, and then (usually) dried. Primed seeds are essentially held in phase II of germination by these restrictions in water potential, or because of insufficient time. Phase III water uptake and seed germination is achieved upon subsequent sowing and rehydration (Bennett *et al*. 2013).

Seed priming is most extensively commercialized in the field seeding or plug transplant production of tomato, pepper, onion, carrots, leek and the production of ornamental plants including begonia, Viola, cyclamen, primrose and many herbs. Priming is also commonly used with seeds of sugar beet, some turf species, and has been used for decades to circumvent seed thermodormancy in lettuce and other species (Hill *et al*., 2008). Several methods have been proposed to regulate water availability (as a liquid or in the vapor phase) to seeds. Three basic systems used to deliver and restrict H_2O, and supply adequate amounts of O_2 to seeds are (i) osmopriming, (ii) matrix priming, and (iii) hydropriming. All three systems can be modified for research use or for commercial use as batch processes. Commercial priming systems can handle seed quantities from tens of grams up to several tons at a time (Ebrahimi *et al*., 2014; Golezani, 2013; Gong *et al*., 2013).

Advantage over fluid drilling: Seeds can be handled in manner similar to the conventional seed and the process can be performed by a seed company.

Recent advances:

- More advanced form of seed priming is Solid Matrix Priming (SMP) in which seeds are mixed with a solid material and water in known proportion (Harman and Nelson, 1994 and Rogis *et al*., 2004).
- Bioprotectants and/or chemical pesticides may be used in conjugation with solid matrix priming. These materials may be added first to seeds as slurry followed by the addition of solid particulate and water (Taylor and Harman, 1990).

Seed treatment with beneficial microorganisms: Seed treatment with beneficial microbes is becoming increasingly important (Howell *et al.*, 1997). Treatment of leguminous seeds with *Rhizobium spp*. is well known for many years for nitrogen fixation. *Azospirullum* and other nitrogen fixing bacteria are being investigated for the same purpose. In principle, the potential for control of seed-borne diseases by microbiological products is also good, and the potential of a number of products has been tested (e.g. *Clonostachys rosea, Gliocladium catenulatum, Trichoderma harzianum*, *Chaetomium Enterobacter spp*. *Bacillus*, and *Pseudomonas chloraphis* (Jensen *et al.*, 2001; Jensen *et al.*, 2004). Biopriming techniques involve the addition of beneficial rhizosphere microorganisms in the priming process, either as a method for efficient delivery to the crop or to control pathogen proliferation during priming itself. Application methods influence the density and uniformity of BCA's on a seed. Biopriming, bio-osmopriming, drum priming, solid-matrix priming (SMP), and specialized pellets/ coatings have been suggested as promising techniques for uniformly applying BCA's to crop seeds (Harman and Taylor, 1988, 1998; Lewis *et al*., 1987; Khan, 1992; Bennett *et al*., 1992; Kubik, 1995; Pill, 1995; Warren and Bennett, 1997). Solid matrix priming, osmopriming, and hydropriming methods have all been employed to increase beneficial microbial populations on the seed. Compatibility of these microbes with chemical seed treatments, inoculants, and other additives can vary. Microbial formulations, quality control, delivery systems and costs of registration have slowed commercial use of biopriming to date **(**Callan *et al*., 1997; Milus and Rothrock, 1997; Moeinzadeh *et al*., 2010; Rhodes and Powell, 1994**)**. Biological control organisms continue to present, however, a unique approach for alternative control of soil pathogens and managing soil borne diseases.

Application methods (vary from agent to agent)

- Regardless of organism used one of the important criteria for successful biological seed treatment is the method for their application.
- Biologically active bacteria are applied as cells to seeds, fungi as mycelial fragments, sexual or asexual spores to the seeds.
- Application methods are varied extend from bacterially inoculated peats for the introduction of Rhizobia onto seeds to simple slurry application containing biocontrol inoculum.

Improved technologies

- Another area of investigation is the application of fluid drilling or gel seeding technology with biological control seed treatment. Fluid drilling offers an ideal system for delivery of a biocontrol agent such as *Trichoderma* for control of soilborne disease problems (Fisher and Conway, 1984)
- A method where an aqueous binder containing fungal spores is sprayed on seeds followed by the deposition of solid particulate material to give a double layer, allowing a slower rate of release of bioprotectant (Taylor and Harman, 1990; Taylor *et al.*, 1991).
- Australian company, Seed Distributors (2008) uses an advanced multiple polymer for coating seeds (Gold Strike®) that protects the nitrogen fixing Rhizobia from less than ideal conditions such as sunlight, acid soil or fertilizers assuring their proven viability in the field (Seed Distributors, Science Based Pasture, 2008).
- Bacterial and fungal bioagents also have been applied to seeds using a film coating technique and fungi have been pelleted onto seeds by commercial method (McQuilken *et al*., 1990; Rhodes and Powell, 1994).
- System such as SMP have been developed to increase the biocontrol organisms per seed and to enhance seed performance (Carlos *et al.*, 1993; Harman and Nelson, 1994; Taylor *et al*., 1988; Rogis *et al*., 2004).
- Zhang *et al.* (1996) have shown that treating cotton seeds with G4 and G6 strains of *Gliocladium virens*

and the GB03 and GB07 strains of *Bacillus subtilis* suppress the incidence of Fusarium wilt of cotton in soil infested with *Fusarium oxysporum* f. sp. *vasinfectum* and *Meloidogyne incognita* under green house conditions.

Future bioprotectants for seed treatment: The efficient use of microorganisms to combat plant diseases by their application in seed treatment requires the development of biological control system that are effective, reliable and economical (Harman, 1991). To a certain extent these requirements have been achieved for some biocontrol agents who are in the final stage of large scale production, field testing and registration (Taylor and Harman, 1990) and others are beginning to be used commercially (Harman and Nelson, 1994).

Growers can raise healthy crops and increase the crop yield by treating seeds with recommended chemicals results in minimize the use of pesticides. Although, seed treatment pesticides (Table 3) have been extensively used at commercial level for a wide range of crops (TNU Agritech Portal, 2013) and the use of chemical seed treatments will undoubtedly continue.

Future prospects: Research into new seed treatment technologies is one of the fastest growing sectors in the global crop protection market with all the major agrochemical companies investing heavily in this area. As pressure increases to make agricultural production safer and more environmentally sustainable there is an increasing focus today on introducing plant protection technologies that can be introduced into the soil via seed. There has always been a lot of research and development undertaken for products in the huge global grain market, increasingly new seed treatment products will be developed for the pastoral market particularly as this market grows internationally.

In recent years, a lot of studies have been done on invigoration of seeds to improve the germination rate and uniformity of growth and reduce the emergence time of and also manage pest/diseases (soil and seed-borne) in many vegetables and some field crops. Scientists have developed a number of methods to reduce the use of pesticides, often driven by environmental reasons (Basra *et al*., 2003). Fungicide treatment of seeds is an area where it may be possible to reduce the quantity of chemicals used by limiting treatment according to the need. By relatively simple tests for seed borne diseases, treatment may be limited to the infected lots only e.g. cereal seeds are produced in relatively large quantities and therefore, if only a small proportion of seed lot require treatment then the quantity of fungicides used could be reduced. Further research on the relationship between seed infestation levels and disease development under natural conditions is required. To minimize the risk of disease threshold levels must be developed for the environmental conditions in which seed is sown.

Some examples of successful use of these prospects

- In Sweden, regulations limiting the use of seed treatments for cereals introduced in 1965. Today seed health testing of cereal seeds is compulsory in Sweden, but the use of fungicide treatment is based on recommendations.
- In 1990, a voluntary scheme for the reduction of the use of seed treatments was introduced in Norway and led to a significant reduction in the use of such products (Scheel, 1997).
- These types of rules and recommendations should also be formulated and implemented in India to reduce the cost of production and pesticide hazards.

Conclusion

This review covers briefly about seed treatment, methods and technologies starts from basic dressing or coating with simplest crude methods and a continuous progress in technological advancement is achieved with time. Moreover, advanced technologies of seed treatment viz. film coating, pelleting, priming etc. came in existence to refine and overcome some limitation or drawback of previous technologies. Seed treatments increase precision and effectiveness of crop protection product by reducing the applications rate of pesticides applied to the land area and hence, it is a leading technology in precision agriculture in present days. After knowing about seed treatment we can say that it will become practical, inexpensive and an easy method of micronutrient delivery (seed enhancement) by advanced technologies of seed priming or seed coating especially by small landholders in developing countries. Future development and commercial use of seed treatment technologies is dependent on important factors such as economic, social, environmental safety and practical utility for that particular crop. For that reason, future research may be more focused on advanced physical (microwave, ultrasound, ozone treatment) and biological (biopriming, SMP) methods of treating seeds alternative to chemical seed treatment. Advances in seed treatment technology will refine existing treatment strategies and future research should be focused on biological seed treatments in addition to chemical treatment using microbial inoculants as diseases and pests suppressing and/or seed enhancing materials which will be applied to seeds either alone or in combinations. The seed treatment then becomes a system rather than merely a component added to seeds. At last, it can be said that seed treatment must be an initial step of raising crop and has a pivotal role in sustainable crop production which cannot be ignored.

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