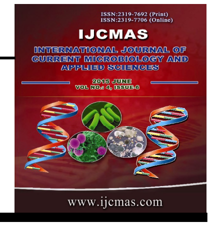
Int.J.Curr.Microbiol.App.Sci (2015) 4(6): 737-752

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 4 Number 6 (2015) pp. 737-752**
http://www.ijcmas.com



Review Article

Post Harvest Management of Fungal Diseases in Onion - A Review

Vinay Kumar*, Neeraj, Sunil Sharma and Narashans Alok Sagar

Department of Agriculture and Environmental Sciences
National Institute of Food Technology Entrepreneurship and Management-Sonepat, Haryana-131028, India

**Corresponding author*

A B S T R A C T

Onion is one of the highly perishable vegetable in India. It is highly valued as flouring agents. The reason for the success of onion in agriculture is its ability to be stored for long period. It can be stored up to about eight to ten months provided; it is treated accurately at its pre and post- harvest stages. About 35-40 % onion is lost due to damage caused by storage diseases. The fungal bulb rot imparts to about 15-30 % losses during storage of different varieties. There are diverse fungal pathogen species like *Aspergillus* spp, *Penicillium* spp, *Alternaria* spp, *Fusarium* spp, *Rhizopus* spp., *Colletotrichum* spp., *Pseudomonas* spp., *Lactobacillus* spp., *Erwinia* spp and *Botrytis* spp which attacks onion bulb during the post-harvest storage period. Amongst all *Aspergillus* spp (Especially *A.niger*) is the most virulent fungal pathogen in the field and during the post harvest storage. The preventive approach of using conventional fungicides to reduce the post harvest losses is not sufficient to provide safe onion and onion products for human consumption and may be hazardous for the human health due to residual impact issues. Therefore, it is essential to develop strategies to minimise the onion losses during storage by the potent application of plant derived compounds or in the form of diverse bio fungicides. The nano bio fungicides can become opportunity to counter and manage fungal diseases of onion.

Keywords

Onion,
Post harvest losses,
Fungal diseases,
Management

Introduction

Onion is one of the potential foreign exchange earners for a country like India, as it is second largest producer of onions after China, producing 1.6 million MT annually FAO(2012). Though India ranks first in terms of the area under onion cultivation in the world and second in its production (Fig.1).The productivity is still quite low as compared to other countries Anonymous, (2001). The productivity of onion in India is 14.35 t/ha which is at least 5 times lesser as compared to republic of Korea (66.16 t/ha), about 4 times less than USA (56.13 t/ha), Spain (55.21 t/ha), Netherland (51.64 t/ha) and Myanmar (46.21 t/ha) Chengappa *et al.*, (2012). It is one of the important ingredients of the daily diet facilitating a constant year round consumer demand. It is cultivated during kharif, late kharif and Rabi seasons as an important crop and is used in raw form as salad and also cooked as vegetable Singh *et al*., (1994).Onion is good source of minerals, vitamins, Polyphenol and a number of phytonutrients.It lower blood pressures and prevents some kinds of cancer. There are three main seasons of onion production namely-kharif, late kharif and Rabi.

Kharif produce imparts 15-20% production and is available in the market from October to December, whereas the late kharif produce which comes in the market from January to March accounts for 20-25% production followed by the Rabi crop which is harvested in April to June which accounts for 60-65% production. The Rabi season onion is only kept for storage till October - November due to its better storability and is made available steadily for domestic as well as international markets.

The onion producing states in India includes mainly, Maharashtra, Karnataka, Gujrat, Bihar and Madhya Pradesh wherein, 32.6% of the total production is contributed only by Maharashtra, NHRDF (2012). The uncontrolled market demand with the advent of the diverse processed products of onion in the market propelled the cultivation of onion on commercial scale, which has led to a sizable increase in acreage and production .The imminent threat of storms hails and heavy rains have always been a concern for the onion growers throughout the year. Due to rains and hailstorms in Maharashtra the acreage and production of Onion declined in 2012-13 (Fig.2). Despite the achievement in production technology and availability of good varieties of onion, the post harvest losses during storage is still an ailing cause which leads to significant qualitative and quantitative losses during storage upto 25-30 %. The onion post-harvest losses were estimated worth Rs 600 crores is found to be due to desiccation, decay and sprouting, Kukanoor,(2005). The rationale behind such post-harvest losses till today is the unavailability of good storage facilities during post-harvest storage phase. Their seems a big gap between the storage facility and the storage capacity which is ultimately leading to the unforeseeable post-harvest decay and deterioration of onion bulbs.

The cold store capacity for fruits and vegetables in India is over 300 lakh million tonnes. Out of which most of the cold storage facilities are used for storage of onion and potato harvest and at tonnes. Post harvest losses in onion are approx Rs 1000 crores annually due to desiccation, decay, and sprouting etc, ASSOCHAM (2012). V.Anbukkarasi *et al*., (2013) reported that during off-season the efficient storage facility for onion plays an important role for the consumers as well as for the producers which ultimately prevents serious losses due to rotting and sprouting.

Post-harvest losses in onion

Storage is one of the important aspects for post harvest handling of onion. The storage condition extends the period of availability of fresh onion by arresting the metabolic breakdown and decay. It is achieved by controlling the Relative humidity and Temperature. The storage life of onion is depends on different parameter *viz.* Physiological activity, Biochemical activity, Microbial invasion (Table1).

Inadequate and improper field curing after harvest, infection by different pathogen, sprouting and also poor storage methods being practiced by the farmers are the main reasons of prevailing losses. In general, the losses due to reduction in weight, sprouting and rotting (decay) were found to be 20-25, 4-5, and 10-12 % respectively, Panday,(1985).In India, currently about 35-40 %of the onion is estimated to be lost as postharvest losses during various post-harvest operations including handling and storage, Anbukkarasi *et al*.,(2013).

Onion suffers from many diseases from pre harvest to post harvest period. They survey conducted at the international level revealed that about 35-40 % onion is lost due to damage caused by different diseases, Gupta and Verma(2002). A number of microorganisms (Table -2) are responsible for bulb rotting of onion, but among them, fungi are the main causal agent responsible for pre and post harvest period losses in the onion, Currah and proctor (1990). The tropical and sub-tropical climate regime prevailing in India, strew (1975). It makes it prone to the development of various fungal pathogens of different genera and species and in turn leading to the damage by causing rot during the storage. However, no detailed studies have been found to identify genera or species of fungal pathogens which causes rotting of onion in India.

So, Identification of pathogens which causes diseases in onion is essential for effective inhibition of target parhogens.Various species of *Aspergillus* pathogens are reported to cause blue mould on onion bulb during storage. The blue moulds are frequently isolated from stored diseased bulbs of local cultivars of onion, Hussain *et al.,* (1977). *Aspergillus niger* is able to produce mycotoxin which reduces the quality and quantity of food products and feed-stuff which is a potent hepatic-carcinogen in humans and animals, Paster *et al.*,(1995); Beltmont and Carjaval, (1998); Sahin and Korukluoglu,(2000); Candlish *et al.*,(2001); Galvano *et al.,*(2001); Juglal *et al*.,(2002); Soliman and Badeaa, (2002); Rasooli and Abyaneh (2004); Sibi *et al.*, (2012).

The fungus causing black mold is the main member of *Aspergillus* and is predominantly a plant pathogen responsible for post harvest deterioration of stored food materials, Marziyeh Tolouee *et al*., (2010).It is responsible for the deterioration of agricultural product during pre and post harvest stages. It affects the availability of onion to domestic and international trade. The infestation of fungi causes spoilage and ultimately decreases the qualitative attributes and quantity of food (Candlish *et al*., 2001; Galvano *et al.*, 2001; Soliman and Badeaa 2002. Rasooli and Abyaneh., 2004).Being saprophytic and filamentous in morphology *Aspergillus niger* resides and perpetuates in soil, forage, organic debris and food products causing black mold disease during post harvest stage of onion bulbs, McDonald *et al*., (2004).

The most favourable temperature conditions for the growth of the fungus is 28°C-34°C followed by the warm and moist conditions eliciting infection,Tysoni *et al*., (2004). The contamination of pathogens begins at germination stage and remains up till storage period, Hayden *et al.,* (1994). The pathogen transmission is by infected soil or seed and the infected bulbs shows neck discoloration along with black coloured mycelia and the hiding spores in the outer dry scales Sumner *et al.,* (1995).Chemical treatment is found best to inhibit Black mold and other fungal pathogens disease in the onion bulbs, Grinstein *et al*., (1992).

Preventive approaches for fungal diseases during storage

Synthetic fungicides

There are more than 50 synthetic fungicides which are recommended for reducing storage losses in onion. Various synthetic fungicides have been frequently used to prevent Pre and Post harvest fungal diseases *viz* carbendazim, Bronopol, Mancozeb, salicylic acid, Bavistin, maleic hydrazide. It was revealed the pre harvest spray of maleic hydrazide @ 2000 ppm+carbendazim@ 1000ppm at 30 days before harvest of onion bulb reduces the rotting and physiological losses and also enhances the shelf life of onion bulbs (up to six months) and improved the quality parameters like TSS content, total sugar, reducing sugar and sulphur content, Anbukkarasi, (2010).

The maleic hydrazide was banned by government of India during the year 2009 owing to its adverse affects. For the inhibition of different types of fungal pathogens there are many applications of fungicides that have been applied for a long time like Benzoyl and Carbendazim at 0.5 per cent showing better control of neck rots**,** Ali and Shoabrawy., (1979).

Falisolan (Carbendazim 60% + Bronopol 6%),Garcia,*et al.*,(1997) is most effective for reducing storage diseases due to *Aspergillus species*, *Fusarium species* and *Botrytis species* and also reported that disease prevalence increased drastically during third month of storage. It was also found that that post harvest spray of 0.25% mancozeb or 0.1 % carbendazim or benomyl were helpful to reduce storage losses for six month storage, Ranpise *et al*., (2001).

Pre-harvest foliar application of Mancozeb @ 0.25 at 30 days after transplanting and repeated at fortnightly interval was adjudged better in reducing the fungal diseases and increases the onion yield in Karnal area of Haryana during Rabi season ,Anonymous, (2009).Storage losses due to fungal pathogen have been reported to be reduced by 40% by spraying of carbendazim 50% WP as pre-harvest application**,** Rajapakase *et al*., (2002).However, Bose *et al.,* (2003**)** revealed that fumigation with sulphur dust before storage minimizes losses and sustain quality of onions in storage.

It was found that combined application of carbendazim and maleic hydrazide at concentration 1000 and 2000 ppm respectively reduced the %age of rotting, fungal infection as compared to the individual treatments in onion crop, Sable, *et al.*, (2004).The harvested bulbs were artificially inoculated with *A. niger* and *P. digitatum* following pinprick method and stored for three months under ambient condition (27±10C). % disease reduction over control was recorded at fortnightly interval. Against black mold, carbendazim 0.1% (Bavistin) recorded maximum of 93.20 % reduction in disease 15 days after storage (DAS) and 56.91 % at 90 DAS.

Carbendazim at 0. 1% concentration was found to be most effective when applied as a post-harvest dip. In addition, post-harvest fumigation of onion bulbs with sulphur dioxide for four hours or dipping the bulbs in acetic acid at higher concentration (0.4 %) distinctly reduced the *Aspergillus niger* incidence,R.Srinivasan.,(2006). The post harvest application of carbendazim (0.1%) was effective in controlling spoilage during storage period. The carbendazim recorded 100 % reduction in black mould and 90.7 % blue mould diseases compared to control (Raju, *et al*., 2007).Application of Bavistin (0.1%) proved the effective during short storage storage; whweras sulphur dust fumigation was most effective for long storage of onion, chavan *et al.,* (1992).

The extensive use of synthetic fungicides increased the resistance of the pathogens, in addition it is not safe over public concern over food and environmental safely, therefore we have to develop the alternative methods which potentially safe to human health and environment for control the diseases (Alabi *et al*., 2005).

Bio fungicides

Natural bio fungicides extracted from various plant parts or microorganisms may provide an alternative to synthetic fungicides. Over the year lots of efforts has been devoted to the search for innovative antifungal materials from natural sources Karapınar,(1989);Topal,(1989); Paster *et al*.,(1995);De *et al*.,(1999); Nielsen and Rios, (2000);Galvano *et al.,* (2001); Yin and Tsao,(2001); Juglal *et al*.,(2002); Soliman and Badeaa, (2002);Onyeagba *et al*.,(2004); Boyraz and Ozcan,(2005); Hacise ferogullari *et al.*, 2005.

The application of different synthetic fungicides to control post harvest diseases of onion is a common practice but due to their toxicity and genesis of pathogen resistance facilitates the need for developing fungicidal formulations originated from plants to control fungal pathogens, Elad., (2000). Naguleswaran *et al.*, (2014) found that in a field experiment, bulb treatment together with foliar application of *Trichoderma viride* improves the yield as well as yield related parameters such as, basal diameter, circumference of bulb, mean number of bulb per bunch.

The finding is of vital importance to manage the fungal disease in red onion effectively by using plant doctor fungi *Trichoderma viride or* other *species* without the use of dangerous synthetic fungicides.

In the same year it was reported that several pathogens attack onion crop in previous section which cause many losses in yield, one of the important causal pathogens is Botrytis allii, Hussein *et al*., (2014) .The different *Trichoderma spp*. were tested and found to suppress the growth of *B.allii* to different degrees. The results of the antagonistic capability of *Trichoderma spp*. showed that *Trichoderma viride* caused the highest reduction of the growth compared to other species, 86%, 84% and 85% for *T. viride* and *T. harzianum* respectively. In case of *T. viride* as biocontrol agent it worked well under greenhouse conditions but these results are required to be confirmed by on-field study. Amongst the different fungi *Trichoderma spp.* has been reported to have greatest impact on the pathogens, McLean., (2000).

It is also reported that the crude extracts of *Moringa oleifera* has antifungal properties. They used the ethanol extracts of leaves and stems of *Moringa oleifera* to control the strain of *Aspergillus niger*. Both the plate and broth assays were used at different concentration e.g.12.5%, 25%, 50%, and 75% of extracts in Potato Dextrose Agar and Potato Dextrose Broth. The inhibitions of *Aspergillus niger* by the application of 75% concentration of leaf extract of *Moringa oleifera* Arowora *et.al.,*(2014). So, it is using as bio protective agent on onion rot which is serves as good option to chemical control.

It is reported that some pathogens also act as antagonistic effect like *Penicillium* species may used as biological control agents against onion fungal pathogen *Aspergillus niger,*Ibatsam Khokhar, *et al.*, (2013). *Penicillium roqueforti* and *P. viridicatum* greatly inhibited the growth of *A. niger* by 66% and 60%, respectively. Different Spices have potential antimicrobial properties against post harvest diseases to control onion black mold using Indian culinary spices under in vitro conditions. Various plant parts of Indian cooking spices have been used for antifungal assay. It was also selected for Phyto- chemical analysis.

First round antifungal screening exposed that among fourteen spices tested, cinnamon, clove, pepper, cardamom star anise and stone flower were exhibited inhibitory activity against the black mold.

Different concentrations of the extracts ranging from 15 to 120 mg/ml were prepared and minimum inhibitory concentration (MIC) values were determined considerable inhibitory action was found at 15mg/ml concentration for cinnamon and clove. Stone flower at 30mg/ml was able to inhibit the pathogen and moderate inhibition was found in cardamom Sibi *et al*., (2013).

From the rhizosphere of different plants species fourteen *Penicillium* species were isolated to explore the antifungal effect of *Penicillium* species against onion black rot pathogen *Aspergillus niger* Ibatsam *et al*., (2013).After study it was found that these isolates showed very high antagonistic effect on the growth of *Aspergillus niger* mycelium .*P. viridicatum* greatly inhibited the growth of *A.niger* by 66% and 60% respectively. It was also found that *Penicillium* species completely overgrew the of *A.niger* colony.

Few Researchers investigated the phyto-chemical profile and effects of Plumeria latex against the postharvest fungal pathogens of sweet oranges. Post harvest fungal diseases of oranges such as *Aspergillus niger*, *A. fumigatus, A. terreus, Penicillium digitatum and Rhizopus arrhizus* were tested aligned with various extracts of Plumeria latex,Sibi *et al.*, (2012). Antifungal effect of the extracts recorded the important inhibitory activity in opposition to *Aspergillus terreus* and *Penicillium digitatum* by the petroleum ether extract. Being for the most part effective on all species, *Plumeria obtusa* was create to have impending antifungal properties followed by *P. rubra* after five days of incubation period.

Novel preventive measures

Newer options are to be developed to find alternative options for synthetic fungicides. In a novel approach researchers reported that nanoparticles has the potential abilities to inhibit post harvest diseases of fruits and vegetables. Different types of Nanoparticles are reaching by the researchers to get the better result and take place the synthetic fungicides.

Silver nanoparticles

Othman *et al.*,(2014) observed the effects of silver nanoparticles (AgNps) biosynthed through *Aspergillus terreus* (KC462061) for inhibition of growth and aflatoxin production by five isolates of *A. flavus.* The results showed that all five *A. flavus isolates* were inhibited by different concentrations of silver nanoparticles but the most excellent inhibition by 150 ppm with different significantly. Ag NPs inhibited the growth of *A. flavus* by disturbing cellular functions which caused deformation in fungal hyphae. AgNPs cause decrease in spores number, abnormality and hypertrophy, these special effects lead to destroyed and damaged of spores. Gajbhiye *et al*. (2009) revealed that combination of nano particles of silver and antifungal agents like fluconazole can increase antifungal effectiveness of disinfectants.

The function of microorganisms in the synthesis of silver nanoparticles (AgNps) emerges as an eco-friendly and sustainable approach. San *et al.*, (2013) reported the antimicrobial property of silver nanoparticles synthesised through reduction with mycelia and culture of *Schizo phylum* and silver nitrate. The antimicrobial activities of silver nanoparticles are tested against *Aspergillus niger, Staphylococcus epidermidis, Staphylococcus aureus,* *Escherichia coli,* and *Candida albicans*. Results showed that silver nanoparticles synthesised by interaction silver nitrate with mycelia fungus, when treated with *Staphylococcus aureus* and silver nanoparticles synthesised by interaction of silver nitrate and culture supernatant treated with *Staphylococcus epidermidis,* gave the largest inhibition area.

In the same year, Khadri *et al.,*(2013) develop potential anti-microbial particles of silver nanoparticles by green synthesis an eco-friendly approach to conventional chemical synthesis. The enzymatic mechanism of the olive seeds has been subjected to generate silver nanoparticles and test the efficacy as antifungal agents before characterizing physical properties using FTIR, UV-Vis and TEM analysis. Silver nano particles were proven to inhibit the growth and development of mycelia of *Aspergillus niger*.

The antifungal activity of composite films, Ag nanoparticles (NP) and pullulan against *Aspergillus niger*. These new materials were prepared as transparent cast films (66–74 μm thickness) from Ag hydrosols containing the polysaccharide Pinto *et al.,*(2012).Fungal growth inhibition was observed in the incidence of such silver nanocomposite films. Moreover, interruption of the spores' cells of *A. niger* was probed for the first time by means of scanning electron microscopy (SEM).

Lamsal *et al*., (2011) reported the effect of silver nanoparticles against pepper anthracnose under different concentrations and silver nanoparticles were applied at different concentrations to determine the *in vitro* antifungal effects and simultaneously in the field conditions. The application of 100 ppm concentration of silver nanoparticles created maximum inhibition of conidial germination as well as the growth of fungal hyphae in comparison to control under *in vitro* conditions and under the field conditions showed inhibition of fungal attack before disease outbreak on the plants. The application of silver nanoparticles in the liquid formulation is found to have inhibiting affect at a concentration of 7 ppm against the White Rot of green onion *Sclerotium cepivorum* (Jin-Hee Jung.,(2010).

Copper nanoparticles

Copper nanoparticles have been reported an important role in pathogen inhibition, Prachi *et al.,* (2014). It is reported that antifungal activity of copper nanoparticles against *Fusarium oxysporium* and found antifungal activity of bavistin increases in combination with CuNPs in the cases of *Fusarium oxysporium.* In the same year the antifungal activity of silver (AgNPs), copper (CuNPs) and silver/copper (Ag/CuNPs) nanoparticles against two plant pathogenic fungi *Botrytis cinera* and *Alternaria alternata,* Sahar (*et al.,2014*).

Metal nanoparticles were applied at different concentrations to determine antifungal activities *in vitro.* The application of 15 mg L^{-1} concentration of silver nanoparticles gave maximum inhibition of the growth of fungal hyphae. They assessed the effectiveness of combining the silver and copper nanoparticles. Microscopic study revealed that nanoparticles caused a damage effect on conidia and fungal hyphae. It was reported the antifungal efficiency of Zinc oxide nanoparticles (ZnO NPs) against two pathogenic fungal species, *Fusarium oxysporum* and *Penicillium expansum*. The antifungal activity of ZnO NPs was found to be concentration dependent, Ramy *et al.,* (2013) .Hence, maximal inhibition of Mycelial growth corresponded to the highest experimental concentration (12 mg L^{-1}), where 77 and 100% growth inhibition was observed for *F. oxysporum* and *P. expansum,* respectively.

Sulphur and Zinc oxide nanoparticles

Massalimov *et al.,* (2013) investigated the antifungal effect of micron and nano scale form of sulphur against two types of pathogenic Schutte fungi. The antifungal effects of sulphur particles in field experiment and sabouraud medium have been studied. It was found that in all cases of laboratory as well as field experiment, antifungal activity of nano sized sulphur with an average particle size of 25 nm, 5-10 times higher than the sulphur micron with an average particle size of 8 microns. Choudhury *et al*., (2010) synthesizes Sulphur nanoparticles (NPs) via a liquid synthesis method with the particles size in the range of 50-80 nm in spherical shape. A comparative study of elemental and nano sulphur was done against the inhibition of Aspergillus *niger*. The results showed that nano sulphur is more effective against *Aspergillus niger* than its elemental form.

Srinivasan *et al.,* (2015) investigated the antifungal performance of Zinc oxide nanoparticles against *Aspergillus nigar and Aspergillus flavus*. The pure zinc oxide nanoparticles were found to be efficient fungicide against *Aspergillus niger* but the aluminium droped zinc oxide nanoparticles were active against *Aspergillus flavus.* The zone of Inhibition diameter value of aluminium doped zinc oxide against *Aspergillus flavus* was found maximum 13 mm for 100µg/ml whereas the zone of Inhibition diameter value of pure zinc oxide against *Aspergillus nigar* was found maximum 11 mm for100µg/ml.

Navale *et al.,* (2015) investigated the antimicrobial activities of Zinc oxide nanoparticles (ZnO NPs) against two strains of plant pathogenic fungi *Aspergillus* flavus and *Aspergillus fumigatus*. These antimicrobial data indicates that the ZnO NPs (Size 20-25 nm) are potentially active in the presence of 100 µg/mL NPs. Singh *et al*., (2013) Claimed that zinc oxide nanoparticles do have strong good antifungal activity against selected strains of bacteria and fungus as compared to that of conventional zinc oxide particles. ZnO NPs have been claimed to have pronounced antimicrobial activities than large particles. Antimicrobial/antifungal potential of ZnO on five pathogens (*Escherichia coli, Staphylococcus aureus, Bacillus subtilis, Aspergillus niger and Candida albicans*) and the influence of particles size of these inorganic powders on its antimicrobial /antifungal efficacy were considered in the present study.

Yehia *et al.,* (2013) investigated the antifungal effectiveness of Zinc oxide nanoparticles (ZnO NPs) against two pathogenic fungal species, *Fusarium oxysporum* and *P. expansum*. The maximal zone of inhibition of mycelial growth corresponded to the highest experimental concentration (12mgL^{-1}), where 77 and 100% growth inhibition was observed for *F. oxysporum and P. expansum,* respectively. The antifungal activity of ZnO NPs was found concentration dependent.Wani *et al*.,(2012) studied the antifungal activity of nanoparticles of magnesium, Iron and zinc. It had been investigated under in-vitro conditions and was found that all the nanoparticles at different concentrations brought about significant inhibition in the germination of spores of *Aspergillus niger, Penicillium notatum,* and *Nigrospora oryzae* Berk. However, the highest inhibition in the germination of all the test fungi was observed at higher concentrations followed by lower concentrations of nanoparticles.

Table.1 Different factors impacting the post harvest losses in onion

Physiological activity	Biochemical activity	Microbial invasion
1. Transpiration 2. Respiration 3. Senescence 4. sprouting	1.Enzymatic 2.Softeninf of tissues	1.Fungi 2. Bacteria

Table.2 Source: Onion disease Guide- Seminis® is a registered trademark of Seminis Vegetable Seeds. Inc. ©2012 Seminis Vegetable Seeds, Inc.

Sl No.	Name of disease	Causal agents	Distribution
1.	Basal Rot	*Fusarium oxysporum f. sp. cepae*	Worldwide
2.	Black Mold	*Aspergillus niger*	Worldwide
3.	Black Stalk Rot	*Stemphylium botryosum*	Worldwide
4.	Blue Mold Rot	*Penicillium species*	Worldwide
5.	Botrytis Brown Stain	*Botrytis cinerea*	North America and Europe
6.	Botrytis Leaf Blight	*Botrytis squamosa*	North America and Europe
7.	Damping-Off	*Fusarium species, Pythium species, Rhizoctonia solani*	Worldwide
8.	Downy Mildew	*Peronospora destructor*	Disease occurs worldwide in temperate and cool growing regions
9.	Leaf Blotch	*Cladosporium allii-cepa*	British Isles and Canada
10.	Neck Rot	*Botrytis allii*	Worldwide
11.	Phytophthora Neck And Bulb Rot	*Phytophthora nicotianae*	Brazil and Taiwan
12.	Pink Root	*Phoma terrestris*	Worldwide
13.	Powdery Mildew	*Leveillula taurica*	Brazil, Israel, Italy, Turkey and USA
14.	Purple Blotch	*Alternaria porri*	Worldwide
15.	Rust	*Puccinia allii*	Disease occurs worldwide in temperate and cool growing regions.
16.	Smudge	*Colletotrichum circinans*	Worldwide
17.	Smut	*Urocystis colchici,*	Worldwide
18.	Southern Blight	*Sclerotium rolfsii*	Worldwide
19.	Stemphylium Leaf Blight	*Stemphylium vesicarium*	India and USA, however, the pathogen may occur in other onion growing regions of the world.
20.	Twister	*Colletotrichum gloeosporioides*	Worldwide, although only of significance in tropical and sub-tropical regions.
21.	White Rot	*Sclerotium cepivorum*	Worldwide
22.	White Tip	*Phytophthora porri*	Worldwide
23.	Yeast Soft Rot	*Kluyveromyces marxianus var. Marxianus*	USA

Fig.1 Production of Onion and area under cultivation in world (Source: Indian Horticulture Data base, 2013)

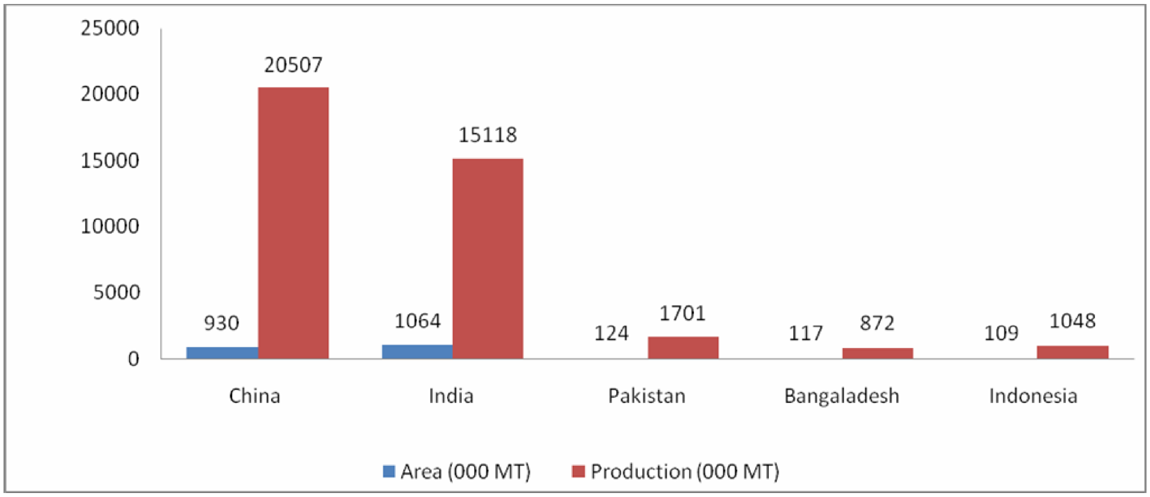
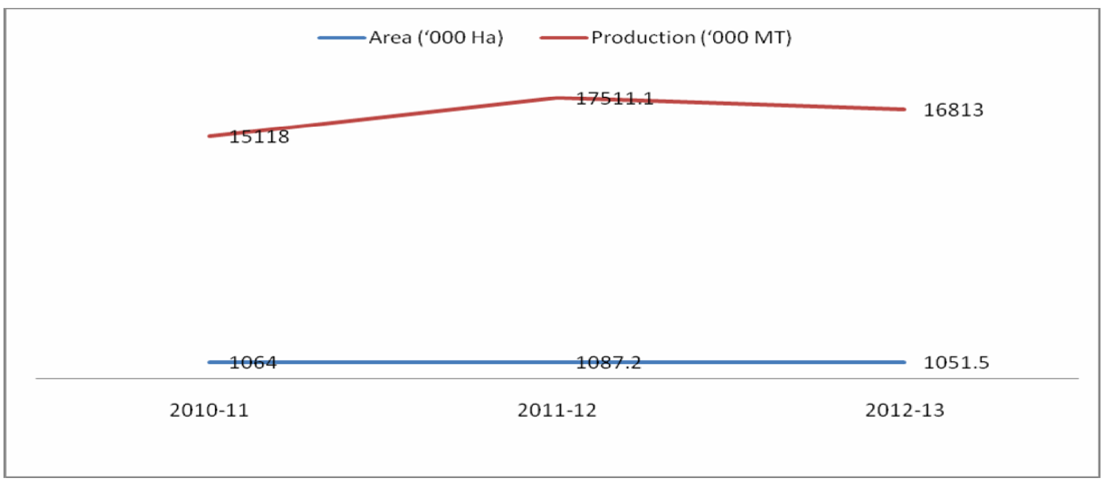


Fig.2 Production of Onion and area under cultivation in India (Source: Horticulture Statistics Division, D/o Agriculture & Cooperation, 2013)



The Nano-MgO at highest concentration was found most effective in reducing the spore germination followed by Nano-FeO and Nano-ZnO at the same concentration respectively. Zinc oxide nanoparticles (ZnO NPs) at the concentration greater than 3moll^{-1} are reported to have significant antifungal activity against the two post harvest fungal pathogens i.e. *Botrytis cinera and Penicillium expansum* during storage, Lili *et al*., (2011).The growth of conidiophores and conidia of *P. expansum* are prevented by ZnONPs ultimately leading to the death of fungal pathogen. Nanoparticles have the important role in controlling the diverse post harvest disease pathogenicity. Researchers are trying to find out diverse nanoparticles for specific post harvest diseases of onion and vegetables crop.

Knowledge gaps

Now days some of the knowledge gaps are present which were identified during this review and there is urgent need for further research are as follows:

1. Limited knowledge is available on application of bio fungicide in Indian farmers.
2. Only *in vitro* results are available and it is not used by the farmers on large scale.
3. Lack of long-term post harvest studies limits the understanding bio fungicides and plant based bio- products for commercial use.
4. No standard application rate of bio fungicide for post harvest diseases management on onion to get maximum significant positive results is available.
5. Farmers have faith only on the use of synthetic fungicide for controlling post harvest diseases of onion.

There is tremendous need for developing environmentally friendly fungicidal formulations against the fungal pathogens worldwide to cope up with the toxic residual impacts of traditional synthetic fungicides on the human health. Diverse techniques for the identification of fungal pathogens must be developed so, as to target the pathogen ailing the Onion bulbs at post-harvest phase. Various fungicidal formulations should be used especially the bio-fungicidal formulations to prevent any type of health hazard to the consumers. The prevailing present challenge is to develop strategies to identify location and region based ecotypes/pathotype sustaining at different geographical locations and accordingly the ways to tackle the post-harvest rotting and decay could be managed by formulating the bio fungicides targeting the region prevalent pathogens successfully. Nanotechnology could also impart in developing eco-friendly, sustainable methodology to mitigate post-harvest losses in onion.

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