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Post haravest loss of fruits and vegetables and their management by biological approaches: A review article

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India is the second largest producer of vegetables in the world next only to China with an estimated production of about 125.9 million tonnes from an area of 7.8 million hectares at an average yield of 16.1 tonnes per hectare. In other terms, India shares about 13.6% of the world output of vegetables from about 2.0% of cropped area in the country (Bhardwaj *et al.,* 2011). Fruits and vegetables in the course of storage or transportation, may serve as a suitable substrate for the development of micro-organisms, may rot and become unfit for marketing (Pelczar *et al.*, 1993; Bukar *et al.*, 2009). The microbial attack during storage and transit is one of the main causes for the deterioration of the fresh produce and therefore, can become a limiting factor in prolonging the shelf life of the harvested fruits and vegetables. Both bacteria and fungi are responsible for post-harvest losses of vegetables, but damages inflicted by filamentous moulds are more substantial due to low pH substrate tolerance (below pH 5), which favours fungal proliferation but inhibits bacterial growth (Burchill and Maude, 1986; Sharma *et al.*, 2009).

A number of viable fungal propagules in the atmosphere and at potential infection sites influence the incidence of post harvest rotting when the fruit is at the ripening stage (Meredith, 1961; Sulai and Khan, 1980; Barkai-Golan, 1981). These decays of fruits and vegetables account for significant levels of post-harvest losses.
Realizing the importance of fruits and vegetables, several pathologists have engaged themselves in studying the post harvest rots of fruits and vegetables including cucumber (Liao and Wells, 1986, 1987), chilli (Muthukumar *et al.*, 2010; Bagri *et al.*, 2011; Sudha *et al.*, 2013), potato (Amienyo and Ataga, 2007; Uppal *et al.*, 2008), onion (Liao and Wells, 1987), brinjal (Joseph *et al.*, 2008; Ghadsingh and Mandge, 2012), turnip (Fatima *et al.*, 2009), mango (Regnier *et al.*, 2008; Abd-Alla and Haggag, 2013), apples and pears (Mari *et al.*, 2003; Calvo and Sozzi, 2009; Maxin *et al.*, 2012), citrus (Fatima *et al.*, 2009; Smilanick, 2011) and tomatoes (Ruelas *et al.*, 2006; Feng and Zheng, 2007; Chuku *et al.*, 2008).

Fungal rots caused by fungi are common post harvest diseases of tomatoes. These pathogens are not only responsible for heavy losses during marketing but also cause considerable changes in quality of tomato fruits. A number of fungal species are known to cause rot in tomatoes but decay of tomatoes are mainly caused by saprophytic pathogen, *A. alternata* (Feng and Zheng, 2007). *A. alternata* occurs in a wide variety of fruits and vegetables under diverse conditions, handling and storage and known to proliferate in tomato fruits affected by sun scald, chilling injury, blossom end rot, faulty blossom scars and growth cracks (Feng and Zheng 2007).

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

The increasing demand by consumers for minimally processed fruits/vegetables necessitates extending the shelf life of these products and is of particular interest to researchers. International agencies that monitor world food resources have acknowledged that one of the most feasible options for meeting future food needs is the reduction of the post-harvest fungal spoilage that may arise during harvesting, handling, transportation and storage (Eckert and Ogawa, 1988). In order to reduce the post harvest fruit losses, massive amount of fungicides are spent every year (Singh *et al.*, 1997; Tripathi and Shukla, 2007) but the public opinion demands a reduction in the use of synthetic chemicals due to the direct exposure to the treated commodities, carcinogenicity, teratogenicity, high and acute residual toxicity, long degradation period, phyto-toxicity and off odour effects, environmental pollution and other side effects on humans. Further, the effectiveness of the post harvest chemical treatment decreases with the appearance of resistant strains (Tripathi and Shukla, 2007; Tapwal *et al.*, 2011). All these concerns have stimulated the need to search some alternative sources for controlling post harvest rots of perishables (Tripathi and Shukla, 2007).

One of such alternatives is natural metabolites produced by plants (Shafique *et al.*, 2006). There are different active principles in plant like crude extracts, alkaloids, peptides and proteins which can be used as botanicals (Abad *et al.,* 2007). Thus, botanical fungitoxicants appear to be one of the better alternatives in plant disease management, as they are known to have minimal harmful impact on the environment and consumers in contrast to synthetic fungicides (Bishop and Thorntop, 1997; Verma and Dubey, 1999).

In view of the positive effect of botanicals in controlling post harvest diseases several researchers have employed them to control various post harvest diseases of chillies (Muthukumar *et al.*, 2010; Bagri *et al.*, 2011; Sudha *et al.*, 2013), groundnut (Kishore *et al.*, 2007; Sahayaraj *et al.*, 2009), mango (Regnier *et al.*, 2008;Tripathi *et al.*, 2008; Abd-Alla and Haggag, 2013), citrus (Singh *et al.*, 2011), potatoes (Amienyo and Ataga, 2007; Uppal *et al.*, 2008; Amadioha, 2012), tomatoes (Hadizadeh *et al.*, 2009; Taskeen-Un-Nisa *et al.*, 2011).

A number of researchers all over the world have used different plant extracts to control various post harvest rots of tomatoes caused by various fungal pathogens. Hadizadeh *et al.* (2009) tested essential oil of *Utrica dioca* (nettle) and *Thymus vulgaris* (thyme) against *A. alternata* causing rot in tomato fruits *in vitro* as well as *in vivo*. Both the nettle and the thyme oils exhibited antifungal activity against *A. alternata in vitro* in terms of spore germination and germ tube elongation. Moreover, their results showed that application of EOs significantly reduced the rot not only in artificially inoculated and wounded fruits but also in naturally infected fruits. Similarly, the inhibitory effects of thyme, sage, nutmeg, eucalyptus and cassia were against *A. alternata* isolated from tomato fruits. Out of all, cassia and thyme both exhibited best antifungal activity against *A. alternata*. Moreover, spore germination and germ tube elongation of the pathogen was also strongly inhibited. The experiments on reducing natural rot development of tomatoes gave similar results (Feng and Zheng, 2007). This reduction in rot development by use of plant products can be co-related with the presence of various phenols that interacted with the food matrix.

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Alcoholic and aqueous extracts of bark, root and leaves of the neem plant (*A. indica*) were used against *Fusarium solani* isolated from tomato fruits both *in vitro* and *in vivo*. The extract of different parts, especially the bark of the plant, gave the highest growth inhibition of the fungus in culture and in checking rot development prior to the pathogen inoculation in the tomato fruits (Amadioha and Uchendu, 2003). Similarly, Amadioha, (2012) tested the efficacy of aqueous extracts of *Ocimum gratissimum* and *Cymbopogan citratus* in controlling the storage rot of tomato fruits by *F. solani* both *in vitro* and *in vivo*. These plant materials inhibited the radial growth of the fungus to varying degrees and was linearly proportional with the concentration of extract used. *In vivo* the extracts were more effective when used as protectant, before infection by the pathogen than as curative, when the disease symptom appeared.

Similarly, *Alchornea cordifolia*, *Cassia alata*, *Moringa oleifera*, *Azadirachta indica* and *Vernonia amygdalina* were tested for their abilities to control tomato fruit rot pathogens *in vitro* and on infected fruits. The mycelial growth was inhibited by both aqueous and ethanolic extracts of *Fusarium verticillioides* and *Macrophomina phaseolina* (Enikuomehin and Oyedeji, 2010). All the plant extracts were also effective in reducing rot incidence of tomato fruits by the pathogens. Suleiman (2010) tested the *in vitro* fungitoxic activity of crude extracts of *Zingiber officinale*, *Garcinia cola*, *Aloe vera* and *A. indica* on *Pythium aphanidermatum* and neem and tobacco extracts against *Pencillium digitatum* and *Rhizopus* sp. isolated from *S. lycopersicum* and found all the plant extracts were effective in decreasing the disease incidence. Recently, Tijjani *et al.* (2014) tried the efficacy of aqueous extract of moringa, lantana, garlic and papaya each with two varying concentrations (40 and 60g/l) against *Aspergillus flavus* causing rot of tomato fruits. The results showed a promising antifungal activity of the crude extracts of these plants against *A. flavus*. Among the various plant extracts with varying concentrations, aqueous extracts of papaya leaves was found to have more significant inhibitory effect on radial growth of *A. flavus* both *in vitro* and *in vivo* better than other extracts.

Antifungal effects of neem seed kernel extract on the post harvest, pathogens, *Monilinia fructicola*, *Penicillium expansum*, *Trichothecium roseum* and *A. alternata* isolated from the infected plum and pear fruits showed significant reduction of pathogens (Wang *et al.*, 2010). Singh *et al.* (2012) confirmed the efficacy of *Capsicum frutescens* and *Zingiber officinale* against *Penicillium digitatum*, *Aspergillus niger* and *Fusarium* species isolated from naturally infected citrus fruits. They found that extracts of *C. frutescens* showed 100% inhibition of colony diameter.

From Jammu and Kashmir, very few reports are available on the use of botanicals for controlling post harvest diseases. Singh and Sumbali (2007) used aqueous leaf extract of *Adiantum capillus-veneris, Thuja orientalis, Eucalyptus globulus* and *A. indica* for the management of fruit rot of apples caused by *Penicillium expansum.* Goswami and Sumbali (2010) reported the efficacy of rhizome extract of *Z. officinale* and *Curcuma longa* and bulb extract of *Allium sativum* and *A. cepa* for effective management of amla caused by *Penicillium funiculosum*.

Among the replete of bio-control approaches, the use of microbial antagonists is quite promising and gaining popularity (Zhang *et al.*, 2005; Sharma *et al.*, 2009). The antagonists micro-organisms that are naturally present on the surfaces of fruits and vegetables, which when after isolation are used for the control of post harvest

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

diseases are called naturally occurring antagonists (Janisiewicz, 1987; Sobiczewski *et al.*, 1996). Droby *et al.* (2009) has well documented the commercial antagonistic micro-organisms available in the global market for the post harvest control of decay in fruits and vegetables. The antagonists are sprayed directly onto the surfaces or are applied by dipping (Barkai-Golan, 2001; Sharma *et al.*, 2009). Moreover, from the available literature, it appears that post harvest application of microbial antagonists is a better, practical and useful method for controlling post harvest diseases of fruits and vegetables (Barkai-Golan, 2001; Irtwange, 2006).

The mechanism under which antagonistic micro-organisms control pathogens in fruits and vegetables is still been researched. Over the years, seven main modes through which the antagonistic microbes fight the disease caused by the fungi have been reported (Sharma *et al.*, 2009). The bio-control mechanisms are achieved through space and nutrient competition, production of antibiotics, attachment, population of the microbial antagonists, direct parasitism and induced resistance. In case of space, the microbial antagonists grow more rapidly and survive under favourable conditions than the disease causing pathogen (Zhang *et al.*, 2008, 2010; Fatima *et al.*, 2015).

In India, several workers recommended the use of antagonists to reduce the growth of fungal pathogens. Kaur *et al.* (2006) used four species of *Trichoderma viz., T. harzianum, T. viride, T. viride* E and *T. virens* against *Colletotrichum capsici* causing rot in *Capsicum annum*. All four antagonists caused significant inhibition of mycelial growth of the test fungus. However, maximum inhibition was obtained with *T. viride* whereas it was least with *T. harzianum*. All the bioagents also had negative effect on spores germination of the pathogen, with *T. viride* being most effective whereas it was least in the culture filtrates of *T. virens*. Mandhare *et al.* (2008) used *Trichoderma* species against *Alternaria* sp. and found it to significantly reduce the mycelial growth. Similarly, Pandey (2010) tested antagonistic behaviour of *Trichoderma viz. T. harzianum* and *T. viride* against *A. alternata*, the pathogen of *Capsicum frutescens.* Results indicated that *T. harzianum* reduced the growth of *A. alternata* by 67.07% followed by *T. viride* causing a reduction of 66.67% as compared to control. Akrami *et al.* (2009) and Khan *et al.* (2014) used *Trichoderma* species to *Fusarium* species isolated from bean and chickpea. Antagonistic potentials of five *Trichoderma* species *viz., T. viride*, *T. harzianum*, *T. koningii*, *T. pseudokoningii* and *T. virens* were tested against some fruit rot pathogens of sapodilla. Percent mycelial inhibition of *T. koningii* (57.70%) and *T. harzianum* (54.4%) proved to be more than 50% antagonistic over control in *A. niger* (Bhale *et al.*, 2013).

From Jammu and Kashmir, there are very few reports on the use of antagonists. Singh and Sumbali (2008) used four *Bacillus subtilis* strains against *P. expansum*, the causal organism of blue rot of apples. Among these, antagonists *B. subtilis* (AG-12) showed maximum inhibition of *P. expansum*.

Brassinosteroids (BRs) have recently been recognized as a new class of phytohormones occurring ubiquitously in the plant kingdom (Clouse and Sasse, 1998). They are growth promoting substances found at low concentration in pollen, seeds and young vegetative tissues in gymnosperms, monocotyledons, dicotyledons and in algae (Sasse, 2003). The endogenous level of BRs varies from tissue to tissue and with the age of the plant (Khirpach *et al.*, 2000). BRs are essential for normal plant development and regulate a range of physiological

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

processes, such as stem elongation, root growth, vascular differentiation, leaf epinasty and reproductive development (Sasse, 2003).

Extensive research has been done on use of BRs to combat a number of abiotic stresses (Ali *et al.*, 2008; Choudhary *et al.*, 2010; Slathia *et al.*, 2012) but there are a few research papers available all over the world on the use of BRs in controlling various pathogens causing diseases in plants. Treatment of potato plants or tubers after harvesting led to a prolongation of the period of deep dormancy of tubers and to enhancement of their resistance to *Phytophthora infenstans* infection (Vasyukova *et al.*, 1994). Field application of 24-epibrassinolide (5–15 mgha^{-1}) to barley plants significantly decreased the extent of leaf disease induced by mixed fungal infection, along with an increase in crop yield (Pshenichnaya *et al.*, 1997). Roth *et al.* (2000) found that treatment with low concentrations of a BR-containing extract of *Lychnis viscaria* L. seeds resulted in enhanced resistance of tobacco, cucumber and tomato to viral or fungal pathogens (tobacco mosaic virus, *Sphaerotheca fuliginea* and *Botrytis cinerea*). Zhu *et al.* (2010) used epibrassinolide to control rot in jujube fruits caused by *P. expansum*. No such other reports of its application in combating post harvest diseases of other fruits-vegetables are available.

The mitigation of pathogenic stress in fruits and vegetables by non-chemical methods might entails a myriad of antioxidant enzymes as well as non-enzymatic antioxidants that interact with one another to resist the effect of invading pathogen. It is, therefore, recommended that this non-chemical, eco-friendly integrated module of plant extracts, fungal antagonists and brassinosteroids be used for effective management fruit and vegetable rots.

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IJARSE
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