

## STUDIES ON PRE AND POST-HARVEST TREATMENTS FOR EXTENDING SHELF LIFE IN ONION – A REVIEW

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Received: 26-06-2012

Accepted: 20-09-2012

### ABSTRACT

In India, presently about 35 to 40 per cent of the onion is estimated to be lost as postharvest losses during various operations including handling and storage. Pre-harvest sprays of growth regulators viz, cycocel, ethylene compounds and fungicides play a crucial role in enhancement of shelf life in onion. The curing techniques like neck cut in onion bulbs and exposure to onion bulbs in gamma radiation for storage are proved to be useful techniques in delaying sprouting and their subsequent deterioration resulting in improved shelf life. Packaging and storage techniques also influence the shelf life of onion bulbs during storage. There is a sequence of physiological and biochemical changes occur in onion bulbs during above post harvest handling operations. The literature pertaining to the above aspects during post harvest handling and storage of onion and garlic bulbs are reviewed in this paper:

**Key words:** Curing, Growth regulators, Packaging, Pre-harvest sprays, Storage.

Onion is one of the potential foreign exchange earners and India stands first in production sharing eight per cent of the world production. In India, onion is produced in an area of 0.527mha, with an annual production of 7.45mt (Anonymous, 2008). Onion, being highly perishable, has poor keeping quality. In India, presently about 35 to 40 per cent of the onion is estimated to be lost as postharvest losses during various operations including handling and storage. The losses are mainly due to reduction in moisture and dry matter. Serious losses occur during storage due to sprouting and rotting. In general, the losses due to reduction in weight, sprouting and rotting (decay) were found to be 20 to 25, 4 to 5 and 10 to 12 per cent respectively (Pandey, 1989; Anonymous, 1994). With this background, the literature available on postharvest handling of onion and garlic are reviewed in this paper.

**Pre-harvest spray of chemicals:** Pre-harvest sprays have been widely applied without impairing the keeping quality of onion. Among the growth

substances/chemicals, maleic hydrazide, ethrel, cycocel, carbendazim and aureofungin treatments as pre-harvest foliar application have gained prominence. These compounds greatly facilitate the maintenance of quality of onion bulbs on storage with respect to inhibition of sprouting, rooting and reduction in the physiological loss in weight. Several chemicals have been tried so far to prolong the shelf life of onions and a few among them are abscisic acid (ABA), gibberellin (GA<sub>3</sub>), auxin and cytokinin (CK) (Abdel-Rahman and Isenberg, 1974), maleic hydrazide (MH), cycocel (CCC) and ethrel (Misra and Pande, 1979), trakephon and ethrel (Pospisilova and Janyska, 1978), paraquat (Bubl *et al.*, 1979) and maleic hydrazide, wondalhid, ethrel, fruitone, offshoot and antack (Iordachescu and Mihailescu, 1981). The maleic hydrazide was banned by government of India during the year 2009. So application of maleic hydrazide for postharvest handling of onion and garlic is not included in this review.

**Cycocel:** Chloro choline chloride (CCC), also called as chlormequat, is chemically known as 2-chloro

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ethyl trimethyl ammonium chloride. Cycocel is one of the most extensively used plant growth retardants to control the vegetative growth of the plants and thereby enhances the production of a number of agricultural and horticultural crops. Cycocel is the most active member of the new group of quaternary ammonium compounds and is anti-gibberellin in its action.

Application of cycocel retarded shoot growth and reduced the internodal length in many crops. Reduction in leaf number and leaf area was reported due to cycocel application in several crop plants. Foliar spray of CCC at 500 ppm significantly increased the diameter, number of cloves per bulb and yield in garlic (Das *et al.*, 1980). Xuang *et al.* (2001) found that the foliar application of salicylic acid one mM l<sup>-1</sup> increased bulb girth in garlic. Onion crop sprayed with cycocel (lihocin) @ 2500 ppm on 75 and 90 days after transplanting showed positive effect by decreasing rotting percentage when compared to control (Anonymous, 2004).

**Ethrel:** Levy and Kedar (1970) first reported that ethephon, an ethylene releasing compound induced bulbing in onions grown under non-inductive photoperiods. Subsequent reports (Lipe, 1975) showed that timing and proper concentration are critical for ethephon to work effectively to increase bulb size and yields. Bubl *et al.* (1979) reported that ethephon increased post-harvest disease and sprouting in onions treated 4 to 12 days before they were lifted for curing in the field. They concluded that foliar desiccation from ethephon tended to increase onion decay in storage. Bubl *et al.* (1979) recorded a lesser increase in the decay of common onion bulbs during storage. Misra and Pande (1979) recorded increase in moisture content with a decrease in concentrations of ethrel and the moisture content with the course of storage. They observed that 2000ppm ethrel treatment produced the lowest content of TSS and highest content of ascorbic acid in common onion bulbs after 30 days of storage. They also found higher levels of reducing sugars at lower concentrations of ethrel in bulbs of common onion and that the reducing sugars showed a decreasing trend during storage.

Application of ethephon 1000 or 3000 ppm resulted in reduced individual bulb weight, total marketable yields and increased incidence of rotten

and cull bulbs in onion (Cantliffe, 1980). Pre-harvest application of ethephon was found to significantly reduce yield by reducing bulb diameter and weight of onion (Thomas and Rankin, 1982). Thompson and Rankin (1983) reported that ethephon at 1000-3000 ppm reduced the sprouting losses in onion bulbs. Pre-harvest spraying with ethrel 2.5 ml l<sup>-1</sup> resulted in significantly lower percentage of rotting and greening onion bulbs after four months (3.0 %; 0.0%) and eight months (5.5 %; 1.3%) storage compared with the control treatment (17.0, 21.3% and 4.9, 13.4% rotting and greening respectively) (Ray *et al.*, 1991). Ethephon (Ethrel at 3.6 or 6.0 l ha<sup>-1</sup>) applied before harvesting on onion cv. Sochaczewska and Blonska mainly reduced sprouting of bulbs during storage at 20°C. (Adamicki, 1998a).

Application of ethephon (1.8 l ha<sup>-1</sup>) sprayed directly onto onion foliage two weeks prior to harvest reduced sprout incidence two-fold compared with controls after 22 weeks storage at 0-1°C (Adamicki, 2005). Qadir *et al.* (2007) revealed that application of ethanol (0.91 g kg<sup>-1</sup>) delayed rooting, sprouting and reduced decay in onion cv. Tazan for one month storage period. Sherpa and Wellington variety of onion bulbs were treated before or after curing (28°C for six weeks) with a single dose of ethylene (10 il l<sup>-1</sup> or 1-MCP (1 il l<sup>-1</sup>) for 24 h at 20°C. These treated bulbs were stored for 38 weeks at 0-1°C. The results showed reduction in the sprouting percentage and increase in the total phenolics, flavonoids and pyruvate content in onion bulbs (Downes *et al.*, 2010).

**Fungicides:** Bavistin (0.1%) spray proved effective during short period of storage, whereas sulphur dust fumigation was effective for long period storage (Chavan, *et al.*, 1992). Repeated spray of mancozeb (0.25%) and carbendazim on bulbs at two months interval reduced rotting losses (Anonymous, 1986). Pandey *et al.* (1994) reported that the application of maleic hydrazide @ 2000ppm in combination with carbendazim @ 0.1 % resulted in less sprouting and decay of onion bulbs. Waskar *et al.* (2000) found that application of pre-harvest spray of maleic hydrazide-40 @ 2000 ppm coupled with the aureofungin at 150 ppm before 15 days of harvesting resulted in low storage losses (33.60 %). The pre-harvest treatments of spraying maleic hydrazide-40

and ethephon (0.2 to 0.3 %) 20-25 days before harvest and post harvest spray of 0.25% mancozeb or 0.1 % carbendazim or benomyl were helpful to reduce storage losses (Ranpise *et al.*, 2001).

Rajapakse and Edirimanna (2002) revealed that application of carbendazim 50 % WP two weeks before harvesting helped to reduce the storage losses of big onion up to 40% due to fungal pathogens. Various chemicals such as streptomycin, bavistin, copper sulphate, salicylic acid, sodium thiosulphate etc. were sprayed fifteen days before harvesting to control rotting and sprouting (Anonymous, 2004). Combined application of carbendazim and maleic hydrazide (1000 and 2000 ppm respectively) reduced the percentage of rotting, fungal infection and sprouting as compared to the individual treatments in onion crop (Sable and Kalebere, 2004). Dipping of onion bulbs in carbendazim (0.1%) was effective in controlling post harvest spoilage during storage period. The carbendazim recorded 100 % reduction in black mould and 90.7 % blue mould diseases compared to control (Raju and Naik, 2007).

Foliar application of mancozeb @ 0.25% at 30 days after transplanting and repeated at fortnightly interval was adjudged better in reducing diseases and increasing onion yield in Nasik area of Maharashtra and Karnal area of Haryana during the *rabi* season (Anonymous, 2009). In onion, Agrifound Dark Red (ADR) variety seed coated with DAP + ZnSO<sub>4</sub> + Bavistin as well as with DAP + borax + trichoderma sown and harvested at Nasik, recorded the highest gross yield (150.00 q ha<sup>-1</sup>) (Anonymous, 2009). Pre-harvest sprays on decay in storage gave better results for 0.02% streptomycin and 0.1 % carbendazim 10 days before harvesting. Application of thiophanate methyl @ 0.1 % + streptomycin or Klorocin @ 0.2 % + Ekalux @ 0.25 % immediately after neck cut and combined with field and shade curing was promising under North Indian conditions, while use of maleic hydrazide @ 2000-3000 ppm 75 days after planting for kharif onions and @ 2500 ppm combined with 0.1 % carbendazim spray 10 days before harvesting in rabi onions gave promising results ([http://www.nhrdf.com/htmlfiles/Onion/oni\\_post.htm](http://www.nhrdf.com/htmlfiles/Onion/oni_post.htm)).

Anbukkarasi (2010) studied the effect of onion plants sprayed with growth regulators at

varying concentrations at 30 days before harvest. The results revealed that growth and yield attributes of onion increased with pre-harvest sprays of maleic hydrazide @ 2000 ppm + carbendazim @ 1000ppm. The same treatment recorded the highest number of leaves plant<sup>-1</sup>, number of bulbs plant<sup>-1</sup>, bulb girth, shoot to bulb ratio, weight of bulb (65.83 and 66.67 g), yield plot<sup>-1</sup> (45.50 and 46.01 kg) and yield ha<sup>-1</sup> (18.96 and 19.17 t ha<sup>-1</sup>), increased the physiological characters like harvest index (0.72 and 0.74), chlorophyll 'a' (0.98 and 1.01 mg g<sup>-1</sup>), 'b' (0.52 and 0.52 mg g<sup>-1</sup>) and total (1.62 and 1.69 mg g<sup>-1</sup>), improved the quality parameters like TSS content (12.18 and 12.32 °Brix at 15 days after harvest and 13.67 and 13.78 °Brix at 30 days after harvest) and soluble protein (19.21 and 19.42 mg g<sup>-1</sup>) and reduced the physiological loss of weight (0.95 and 1.02 per cent at 15 days after harvest and 1.17 and 1.21 per cent at 30 days after harvest) with no sprouting during the first and second season respectively.

**Curing methods:** Proper storage of bulbs is necessary for both consumption and seed production. Onions should not be stored unless adequately dried either in the field or by artificial means. It is necessary to dry the neck tissue and outer scales until they rustle when handled otherwise the bulbs will rot in storage. Sprouting in onion is controlled by temperature and rooting is influenced by relative humidity.

**Neck cut in onion bulbs for storage:** Randhawa and Nandpuri (1966) and Kepkova and Umiceka (1970) observed that onion within their well dried necks stored better than those having poorly dried necks. Udry (1972) reported that a higher incidence of mould development (4.8 to 9.5 per cent) was found in onions stored at -0.6 to 2.0°C with 75 to 80 per cent relative humidity without tops as compared with those with tops (0.4 to 2.0 per cent). Ali and Shoabraway (1979) reported that bulbs with 1 to 2 cm of neck showed less infection and storage loss than those stored without neck. Laul *et al.* (1984) tried different methods of curing to improve the storage life of onion. They reported that natural leaf cover and bunch hanging were found to be the best method in regard to colour development and retention, pungency and reduction in wastage due to storage. Bulbs with 2.5 cm neck cut developed

colour and neck gets sealed completely preventing post harvest losses.

Shaha and Kale (1985) reported that onion cultivars having medium to large bulb weight, greater polar diameter and thin neck had better keeping quality. Sidhu and Chadha (1986) reported reduction in sprouting when harvested bulbs were kept for 15 days for drying with 2.5 cm neck-cut. The necks of the bulbs were completely dried and bulbs developed bright white colour. When the tops were removed immediately after harvest, the sprouting percentage was high (31.50 per cent) than the control (11.00 per cent). In an evaluation of chemicals for control of storage rot of onion bulbs, sulphur dust fumigation was found to minimize the percentage of rotting, while spraying with bavistin, dithane M-45 and streptomycin was effective in that order (Chavan, 1987).

Curing of onion for four days in field by windrow method of curing in shed for 21 days before storage decreased the reducing sugars, which improved the storage life of bulbs, but it did not influence dry matter and TSS and recorded the least storage losses (Anonymous, 1988, 1989 and 1990). Fully cured bulbs with 4 cm neck recorded the least storage losses (Anonymous, 1988, 1989 and 1990). Mondal *et al.* (1990) showed that bulbs dried in sunlight for 2, 4 and 6 days with or without foliage, significantly reduced rotting, weight loss and sprouting in bulbs. Chauhan *et al.* (1995) said that the lowest decay loss (6.21 per cent), physiological loss (15.17 per cent) and total loss (6.21 per cent) were seen in bulbs of 2.5 cm neck cut. Lowest decay loss (5.39 per cent) and total loss (19.43 per cent) were found when bulbs were stored after field curing by windrow method, shade curing with tops for ten days and 2.5 cm neck cut under Karnal conditions. The results are in conformity with the findings reported by Pandey *et al.*, 1992 and 1993).

Wardae *et al.* (1995) carried out storability studies on onion bulbs cv. N-2-4-1 with the use of different recommended practices including covering of storage structure with straw + spraying of 0.2 per cent Dithane M-45 + provision of perforated pipes + grading (medium size bulbs) + neck length 4 cm + shade curing for 21 days + field curing for 4 days recorded low total losses (39.18 per cent) against conventional method i.e. control (54.13 per cent)

after the storage period of 150 days. Chauhan *et al.* (1995) reported 24.23 per cent total losses when windrow method was adopted for curing onion. On the other hand 27.25 per cent total losses were reported when non-windrow method of curing was adopted. They also found that when close neck cut was followed, 29.68 per cent total losses were reported; on the other hand when 1 cm neck cut was adopted 21.81 per cent total losses were reported.

Bhonde (1998) reported that removal of foliage leaving 2.5 to 3 cm neck was found beneficial in enhancing the storage quality which formed very important post harvest step in onion. Small onions were cured in order to enhance dormancy, to seal against water loss during storage and to extend shelf life by limiting the access of disease (Maw *et al.*, 1998). The maximum safe temperature for onion curing at field was 37.8°C for 3-5 days, while artificial curing of onion in creates at 40°C for 16 hrs was found best to reduce the losses (Maini and Chakrabarti, 2000). Onion bulbs cv. N-2-4-1 were given sulphur fumigation (50 g m<sup>-3</sup>) for different durations to reduce the disease infection during storage (Anon., 2000). The optimum temperature of onion storage should be higher than 15°C along with 60-70 %RH, medium sized bulbs with 2-3 cm neck length (Ranpise *et al.*, 2001). Onions lifted at 60-80 per cent top-down, the bulbs field cured and the foliage removed after curing was the simplest method and best compromise to ensure post-harvest onion quality and successful storage (Wright *et al.*, 2001).

Pandey (2001) reported that it was good to leave about 2 to 2.5 cm top above the bulb as such bulbs stored better than close top cut bulbs. Well cured bulbs of onion cv-N-2-4-1 were subjected to sulphur fumigation (50 g m<sup>-3</sup>) for three hours duration and stored at ambient conditions. Black mould infection was significantly reduced to 2.5 per cent compared to control (4.3%) (Anonymous, 2002). Garlic bulbs cv. G-41 were given sulphur fumigation (50 g m<sup>-3</sup>) for three hours after shade curing and cutting of leaves to reduce the diseases infection and rotting of bulbs (Anonymous, 2002). Sweet onion cv. Granex 33 was harvested at late stage of maturity, whereas late harvested onions required only 48 hours of curing and lost only 6 per

cent moisture. Though curing helped to extend the shelf life of sweet onion, it also reduced the mass of onions available for retail (Maw and Mullinix, 2005). Among the different curing methods, curing bulbs under 50 per cent shade (15 days) + tops removed 15 days after harvest resulted in minimum physiological loss in weight (13.56%), sprouting (9.36%), rotting (16.70 %), loss of scales (11.98%) and also maximum in the hardness of the bulbs (10.32 kg cm<sup>-2</sup>), colour development (4.50 per 5.00) and marketable bulbs (67.35%) compared to control (Kukanoor *et al.*, 2006).

Anbukkarasi (2010) reported that combined application of pre-harvest spray of maleic hydrazide @ 2000 ppm + carbendazim @ 1000ppm at 30 days before harvest along with 2 cm neck length of bulbs recorded reduced physiological loss of weight (1.22 and 1.28 per cent) and sprouting loss (0.01 and 0.02 per cent) and enhanced quality parameters like TSS (13.86 and 13.97 °Brix) and pyruvic acid content (2.65 and 2.71 µmol g<sup>-1</sup>) during the first and second season respectively.

**Gamma irradiation:** Elaborate work has been done with gamma irradiation as a means of extending the storage life of common onion. Doses ranging from 2 krad to 100 krad have been tried by several workers (Silva *et al.*, 1975; Kume *et al.*, 1977; Grunewald *et al.*, 1978). There was a general apprehension in the minds of people that gamma irradiation of food material produced some residual toxicity, which was disproved scientifically (Heins, 1975).

**Time and dose of irradiation:** Mullins and Burr (1961) irradiated the onion bulbs at 2 kr two weeks after harvest and found that sprouting was completely inhibited. They also found that irradiation after 11 weeks of harvest, irrespective of the dose, viz., 2 to 250 kr, was ineffective in inhibiting the sprouting. Nuttall *et al.* (1961) tried various doses, viz., 3.2, 4.7, 7.9 and 9.5 kr and in most of the treatments, sprouting inhibited upto 300 days in storage of onion bulbs. Ogata (1973) found that the delay of irradiation after harvest reduced the effect of gamma irradiation on the inhibition of sprouting in onion bulbs. Heins (1975) stated that low doses of gamma irradiation had a beneficial effect on the storage life of onions. Langerak (1975) recommended 75 Krads as the optimal dose for

onions and higher doses intensified discolouration and caused off-flavour.

Kalman (1978) reported that gamma irradiation with intensity of 5 kr inhibited sprouting and reduced spoilage in stored common onions and it was necessary to irradiate the onions grown from seed within three-four weeks of harvest and those grown from sets within five-six weeks. Benkeblia *et al.* (2004) investigated the effects of gamma irradiation doses and temperature on fructo-oligosaccharides of onion bulbs after six months storage. After six months, glucose, fructose and sucrose of control and both irradiated bulbs decreased slightly but not significantly, while temperature and irradiation significantly influenced fructo-oligosaccharides (fructans) of bulbs.

**Effect on physiological loss:** Ali *et al.* (1970) obtained reduced weight loss of the bulbs of common onions irradiated and stored. Similar reduction in weight loss in storage compared to untreated bulbs was also obtained by Silva *et al.* (1975) and Menniti (1977). Curzio *et al.* (1983) reported that the cumulative weight loss over the storage period was about 60 per cent in untreated control but only 23 per cent with irradiated bulbs with 60 CO rays. The weight loss, rotting and black mould infections were lower in cold storage with gamma irradiated bulbs compared with ambient storage untreated onion bulbs (Tripathi and Lawande, 2007).

**Sprouting:** In common onion, sprouting was completely prevented by gamma rays @ 2000 to 3000 rads (Ogata, 1961). Nandpuri (1966) also observed that onion bulbs irradiated with atleast 12,000 units of gamma rays totally checked the sprouting upto eight months.

Ali *et al.* (1970) found that sprouting was controlled by a dose of 8 Krad without affecting the flavour and pungency. Irradiation treatment (6-8 Kr gamma rays) showed no sprouting losses during six months of onion storage (Anon, 1983). Low doses of gamma irradiation have been used to inhibit sprouting and to extend the shelf life of garlic bulbs cv. Colorada (Crocini *et al.*, 1995).

**Effect on bio-chemical changes:** Ghods *et al.* (1976) reported that after irradiation of onion with 0.03 Kgy treatment 30 % of vit-C was lost. Murray (1983) found that onions treated with 0.02 to 0.06

KGy in the presence of air resulted in some conversion of ascorbic acid to dehydroascorbic acid without significantly affecting the nutritional value. Kwon *et al.* (1988) concluded from their studies on a Korean garlic cultivar that immediately after gamma irradiation with 100 Gy there was no difference in the levels of linoleic, palmitic, oleic and linolenic acids, the predominant fatty acids of bulbs. Croci *et al.* (1995) reported that higher carbohydrate and ascorbic acid contents of *Valenciana sintetica* variety of irradiated onion bulbs when compared to non irradiated. The storability of Vit-C in onions irradiated with three different doses of gamma rays and stored at two different temperatures was studied. During storage period, Vit-C decreased over 12 weeks in both control and irradiated bulbs and at both temperatures (Benkeblia and Khali, 1996). Gamma rays affected several chemical components of sprout of cv. Colorado garlic, inducing growth regulators, total DNA, RNA, proteins, soluble carbohydrates and lipids (Croci *et al.*, 1990, 1995; Perez *et al.*, 2007). Bongirwar and Shirsat (2000) reported that gamma irradiation at 60-90 GY inhibited sprouting without affecting TSS, dry matter content, reducing sugars, colour, pungency and flavour strength of onion.

Benkeblia *et al.* (2002) also did not observe any significant difference in total saccharides (glucose, fructose and sucrose) of control and irradiated bulbs stored for six months at 4, 10 and 20°C. More recently, they also reported histological and anatomical changes in garlic sprouts associated with gamma irradiation of the bulbs, followed by storage under controlled condition (Orioli *et al.*, 2004). Perez *et al.* (2007) reported that bulbs of cv. Colorado garlic were irradiated at 60GY of gamma rays and stored for 8 months. The treatment resulted in reduction of lipid, fatty acid content and sprouts growth of bulbs.

#### **Effect of different packaging techniques :**

Packaging has multifunctional roles by serving as symbol of value addition, assurance of quality and quantity and preventing post-harvest losses. The bulb respire and transpires continuously resulting in high weight loss and becomes susceptible to various diseases and spoilage due to inappropriate packaging. In India, the inadequate packaging techniques cause major post-harvest losses (Singh

*et al.*, 2007). Adequate and proper packaging protects the bulb from physical (firmness), physiological (weight) and pathological (decay) deterioration (Yadav, 2003).

Patil *et al.* (1988) found 91.09% total weight loss when bulbs were stored in bamboo baskets for six months. Cured onion bulbs (cv. Agri Found Dark Red) were stored in bamboo baskets under ambient conditions for four months. The lowest percentage total loss (50.47) was obtained with curing in the sun with foliage and storage of bulbs with dried foliage compared with non-cured bulbs (Pandey *et al.*, 2000). Onion bulbs cv. Red Creole stored at 0°C cured through sun-drying and placed in wooden crates retarded bulb rot incidence and reduced post-harvest losses. It was also effective when bulbs were stored at 27°C (Eligio *et al.*, 2002). Onion cv. N-2-4-1 was packed in different packing materials (staking, HSC bags, netlon bags and plastic crates) and stored in different storage methods. The results revealed that overall lowest losses (31.1%) were found in HSC bags and plastic crates kept in control forced ventilated compartments after five month of storage (Anon., 2002).

#### **Effect of different storage techniques on shelf life:**

The physico-chemical constituents during storage of fruits and vegetables have been analysed and reported by many investigators. Post-harvest deterioration of fresh produce could be caused by many factors such as high respiration rate, biochemical changes, physical injuries, water loss and physiological disorders (Kader *et al.*, 1989). Paterson and Wittwer (1953) noticed a reduction in sprouting and root growth of onions previously treated with maleic hydrazide and stored for 18 weeks in ventilated experimental bin or crate.

Yamaguchi *et al.* (1957) observed sprout initiation in bulbs stored at 10 and 15°C. However, no sprouting was observed at 25°C and above as well as below 10°C. Rotting of common onion bulbs in storage was considerably prevented by treating with maleic hydrazide at 2000 ppm. Singh and Singh (1973) reported that onion bulbs stored in wooden boxes recorded 50 per cent weight loss and 40 per cent sprouting after 120 days. Losses to a tune of 30 and 18 per cent respectively due to shrinkage and pest and diseases were observed by Musa *et al.* (1974) when the bulbs were stored for six months in

straw-erected crates. Kak'M' Kova (1975) reported that onions stored over winter in ordinary store attics gave the lowest percentage of bolting and those stored in cellars gave the highest percentage of bolting. Onion cv. Dorate di parma was exposed to 10 Krads of Co60 gamma irradiation in 5, 10, 20, 40 and 80 minutes and then stored in the cold storage ( $10 \pm ^\circ\text{C}$ , RH 65-70%) for three months. Weight loss and number of buds sprouted were reduced significantly in the irradiated onions when compared with control (Farooqi and Donini, 1976).

Menniti (1977) recommended net bags as more suitable than perforated polyethylene bags for onion storage. Total fructans decreased after six months storage independently of temperature, although their degradation was higher at low temperature (Rutherford and Whittle, 1982). Spraying of onion with maleic hydrazide before harvest and storing at 70 to 75 % relative humidity have been recommended to reduce storage losses (Thompson, 1982). Hurst *et al.* (1985) noted a decrease in total sugars of onion kept during six months at 1 and  $4^\circ\text{C}$ , but no variation was noted at  $21^\circ\text{C}$ . Salama *et al.* (1990) reported a decrease in total sugars and glucose in control onions stored for five months at 0, 15 and  $30^\circ\text{C}$ , but fructose increased, particularly at  $0^\circ\text{C}$  compared to maleic hydrazide treated bulbs. Similar results on fructose were reported by Rutherford and Whittle (1982) at  $0^\circ\text{C}$ . Chavan *et al.* (1992) reported that hanging method of onion storage was found effective for short period of 45 days storage, those for long storage (90 days) cage method of storage was effective for minimized bulb rots. The cured onion bulbs were packed in bamboo baskets and kept at room temperature ( $35^\circ\text{C}$ ). The minimum physiological loss in weight, decay loss and cumulative weight loss were observed in cv. Punjab Red Round at 56 days after storage (Kumar *et al.*, 1995). Onion cv. Local Asomia Piaz was stored at dry sand on pucca floor showed the lowest loss in all aspects i.e., sprouting, rotting, physiological loss in weight, total weight loss and better storability in terms of retaining higher percentage of marketable bulbs after 150 days of storage period (Deka *et al.*, 1995).

Yoo *et al.* (1996) revealed that changes in sugar concentration were measured in inner and outer scales of onion bulbs (cv. TG 1015Y) during

storage at 1, 13, 27 or  $34^\circ\text{C}$  for 12 weeks. In the inner scales, fructose, glucose and total sugar concentration decreased as storage temperature increased, while sucrose increased. In outer scales, similar changes occurred but with a less extent. Warade *et al.* (1997) reported that onion bulbs stored in modified storage structure with spraying 0.2 % mancozeb + provision of perforated pipes with storing 45-55 mm bulb diameter + 4 cm bulb neck + shed curing for 21 days + 4 days field curing reduced storage losses upto 32.38 % as compared with conventional method (51.74%). They also revealed that onion bulbs packed in gunny bags and stored in modified storage structure at three months, was observed with minimum storage losses (34.65 %). Adamicki (1998) reported that the 17 onion cultivars stored in an ambient ventilated store and at  $0^\circ\text{C}$  for 6 months. Low storage temperature ( $0^\circ\text{C}$ ) greatly suppressed sprouting, but had no effect on root development.

Ramin (1999) reported that onion cv. Texas Early Grano maintained marketability at temperature of 25 and  $30^\circ\text{C}$  for periods of 3 and 2 months respectively. During the first 3- 4 months of storage at these high temperatures, there was no significant change in pH, TSS, titrable acidity and also showed significantly more weight loss and rotting of the bulbs. In Sudan, mud or straw cottages were used for storing onions. After four to five months storage by this method, 50-60% of bulbs were marketable (Maini and Chakrabarti, 2000). Benkeblia *et al.* (2002) reported that the respiration rate of maleic hydrazide treated onion bulbs stored at 10 and  $20^\circ\text{C}$  was less compared to control bulbs, while the maleic hydrazide treatment did not affect carbohydrate status during storage. Benkeblia *et al.* (2002) noted an increase of fructans, particularly DP 5-8, of onion bulbs after six months at 10 and  $20^\circ\text{C}$ . High dry matter in onion cv. Sherpa when stored in CA (1 % or 0.5%  $\text{O}_2$  with less than 0.3%  $\text{CO}_2$  at  $2^\circ\text{C}$ ) had an improved shelf life (when tested for 3 weeks at  $18^\circ\text{C}$  after 9, 27, and 36 weeks storage) compared with those stored in air condition (Praeger *et al.*, 2003). Pyruvate concentration in onion bulbs cv. Hysam decreased 9 weeks after storage at  $0.5^\circ\text{C}$  in the CA conditions (2%  $\text{O}_2$ , 2%  $\text{CO}_2$ , 2%  $\text{O}_2$  and 8%  $\text{CO}_2$ ), whereas the pyruvate concentration of bulbs cv. Hysam in ambient atmosphere storage increased (Uddin and Mactavish, 2003). Onion bulbs

irradiated at cobalt 60GY were stored under cold storage (0-2°C; 65-70 % RH respectively) for 4 months. The total loss after four months was 50.3 per cent in irradiated cold storage onion as compared to un-irradiated ambient stored onions (87.12 per cent) (Anonymous, 2003).

Benkeblia and Shiomi (2004) measured the respiration rate, soluble sugars, total phenolics and peroxidase activity of onion bulbs treated four weeks at 0°C and stored in the dark at 20°C. These low temperatures also caused a decrease in total phenolics and peroxidase activity. Adamicki (2005) studied the effect of pre-harvest treatments and storage conditions on quality and shelf life of onions and found that controlled atmosphere containing 3% CO<sub>2</sub> and 5% O<sub>2</sub> or 3 % CO<sub>2</sub> and 1.0-2.0% O<sub>2</sub> as well as maleic hydrazide was most effective for inhibition of sprouting during storage and three weeks of shelf life at 20°C. Only 3-10 % of onions cv. Rumba stored in CA (0.5%, 1% or 2% O<sub>2</sub> with 3% CO<sub>2</sub> at 0°C) for 36 weeks had sprouted after three weeks at 20°C compared with 40 % of air-stored bulbs (Adamicki, 2005).

The concentration of the plant growth regulator abscisic acid (ABA) decreased during storage in onions held under CA conditions and it has been postulated that a minimal ABA concentration coincided with the onset of sprout growth (Chope *et al.*, 2006). Storage at 0°C provided the best storage conditions for preserving the quality of cv. Perla garlic for up to 15 days, with a low sprouting index and percentage weight loss as well as good firmness and colour (Barrios *et al.*, 2006). The soluble solids of inner scales and average pyruvate, 3,4-dimethyl thiophene and disulfides content increased during the four week shelf life at 22°C of the onions cv. Walla Walla Sweet (Mikitzel and Fellman, 2007). Onion cv. SS1 stored in CA for 42 days had a lower pyruvate concentration than those stored in air for 42 days (Chope *et al.*, 2007a). Tripathi and Lawande (2007) reported that among sprout suppressant treatments, gamma irradiation of onion showed reduction in storage losses (5-6%) and inhibition of sprouting in cold storage condition as compared to ambient storage condition (20-25%). Chope *et al.* (2007) revealed that the application of exogenous ABA and an ABA analogue (82 -methylene ABA methyl ester; PB1-365) had no consistent effect on the endogenous ABA concentration of onion

bulbs. Bulb ABA concentration decreased during storage and the onset of sprouting occurred at a minimal ABA concentration (ca. 50-120ng g<sup>-1</sup> DW). Chope *et al.* (2007b) found that a single 24h treatment with 1-MCP (1 il l<sup>-1</sup>, 24h, 20°C) after harvest reduced the sprout length and maintained higher glucose and fructose concentrations in onion bulbs cv. SS1 stored at 12°C. The onion bulb (cv. Talaja Red) was stored up to three months under forced ventilated storage structure. During the storage period, TSS, total sugars and pyruvic acid content increased when compared to natural ventilated storage structure (Dabhi *et al.*, 2008). Bufler (2009) reported that treatment with 1-MCP (0.25 il l<sup>-1</sup>, 5h, and 20°C) four weeks after harvest (two weeks drying at 25°C+ two weeks storage at 18°C) reduced the dormancy during storage at 18°C by two weeks compared with control in onion bulbs cv. Copra. Onion bulbs cv. Arka Pragathi cured for a period of 10 days in the field and stored in ventilated room for 30 days recorded reduced storage loss in weight (10.13%), sprouting (1.16%) and rotting percentage (1.16%) (Mahanthesh *et al.*, 2009).

Anbukkarasi (2010) reported that the pre-harvest spray at 30 days before harvest a combination of maleic hydrazide @ 2000 ppm + carbendazim @ 1000 ppm with 2 cm neck length of bulbs stored in low cost bottom ventilated storage structure registered the least physiological loss in weight, sprouting, rotting and total loss, no rooting and improved the quality parameters like TSS, total sugar, reducing sugar and sulphur content of the bulbs. The above treatment also enhanced the shelf life (up to six months), reduced the physiological loss of weight (5.72 and 5.18 %), sprouting loss (0.58 and 0.62 %), rotting, rooting and total loss (6.58 and 6.78 %) and improved the quality parameters like TSS content (17.14 and 17.22 °Brix), total sugar (6.76 and 6.83 %) reducing sugar content (1.44 and 1.49 %) and sulphur content (0.697 and 0.704 %) during the first and second season respectively. In this experiment, ascorbic acid (10.19 and 10.24 mg 100 g<sup>-1</sup>), pyruvic acid (2.48 and 2.53 μmol g<sup>-1</sup>) and also total phenolic content (621.11 and 625.56 μg g<sup>-1</sup>) showed decreasing trend with increasing storage period up to three months. The enzymes such as phenylalanine ammonia lyase, peroxidase and polyphenol oxidase activity also decreased with increasing storage period.



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