Review of best postharvest practices for fresh market green beans

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1. Introduction

Green bean or snap bean or French bean (*Phaseolus vulgaris* L.) pods are vegetables consumed fresh or processed. It is considered a highly perishable vegetable because it is harvested immature and has a high moisture content. Storage life of green bean pods does not exceed 21 days under favourable refrigerated storage. The visual quality of pods is one of the most important quality parameters affected due to rapid deterioration after harvest. Many nutritional and compositional changes occur after harvest and during storage. The aim of this review is to describe the postharvest chain of fresh green beans, focusing on the proper harvest stage, harvesting methods, packaging materials, pre-cooling methods, refrigerated storage, and transportation. This information will be helpful to identify the best postharvest practices and technologies for reducing the loss of quality and nutritional content of green bean pods after harvest and during storage.

Twenty species of green bean (*Phaseolus vulgaris* L.) are consumed by humans, with green bean most consumed. Green bean, French bean, common bean, broad bean, and navy bean are other common names of *P. vulgaris* species. In 2016, the world harvested area of green beans was 155.72 million ha producing 235.96 million metric tons (Food and Agriculture Organization, 2016). World export and import values were US$ 789.23 million and US$ 986.26 million, respectively. Green bean is a good source of important nutrients and bioactive compounds and contains proteins, carbohydrates, fibre, and vitamins A and C (Fabbri and Crosby, 2016).

In most cultivars, pods are harvested at 12-14 days after flowering. At this stage, green bean pods have optimum quality standards of being straight, tender, fleshy, bright green, and having tender green seeds. If pods are left on the plant they begin to mature and pods become fibrous, less tender, lose green colour, and the seeds enlarge, get harder and become mature (Watada and Morris, 1967). Colour of green beans is an important visual quality parameter which changes from bright green after harvest to light green or yellowish colour (Trail et al., 1992). Loss of quality in pods begins immediately after harvest and increases throughout the supply chain.

Yellowing of pods is often due to green pigment degradation (chlorophyll a and b). Unacceptable quality in green bean pods is often related to shrivelling due to moisture loss, decay due to microbial growth, fibre development due to over-maturity, injured pods due to mechanical harvest or rough handling, browning due to injuries caused during harvest, and chilling injury due to storage at lower than the recommended temperature (Cantwell, 2004).

The white paper discusses postharvest handling operations and describes postharvest technologies for extending shelf-life of green bean pods and reducing the loss of quality during storage.

2. Factors reducing green bean quality

2.1. Weight loss:

Moisture loss in the green bean is a major problem causing reduced quality and shelf-life (Qin et al., 2016). Shrivelling and loss of crispness of green bean pods appear to be due to weight loss (Trail et al., 1992). The poor appearance increases with elevated temperatures, low relative humidity, or both (Watada et al., 1987). Unacceptable green beans for marketing is when weight losses are more than 5 % of the initial weight (Robinson et al., 1975).

2.2. Fungal decay:

Gray mould (*Botrytis cinerea*), white mould (*Sclerotinia sclerotiorum*), rhizopus rot (*Rhizopus stolonifer*), and Pythium leak (*Pythium aphanidermatum* and *P. ultimum*) are the most common decays caused by postharvest fungal infections in the green bean pods (Figure 1). Most lead to decay during storage.

Gray mould is considered as one of the most important fungal pathogens causing severe postharvest losses in and vegetables (Aktaruzzaman et al., 2017). Infection by *B. cinerea* often cannot be observed at harvest but symptoms develop quickly under moist conditions during refrigerated storage and transport, even at 0°C (Romanazzi et al., 2016). The most common symptoms of this fungus are water-soaked lesions combined with white to greyish mycelium. Gray mould of snap bean pods (Xera and Valentino varieties) stored at 7±1 °C and 90-95 % RH for 20 days could be reduced by postharvest treatment with potassium silicate, potassium thiosulfate, and potassium sulphate treatments (El-Garhy et al., 2016).

Figure 1. Green been pods showing fungal decay symptoms

2.3. Bacterial and viral infections:

Contamination of fresh vegetables by foodborne pathogens has received more attention due to the presence of the human pathogens *Escherichia coli* O157: H7, *Salmonella, Campylobacter* spp., *Yersinia enterocolitica*, and Norovirus in foods. Snap bean pods could become contaminated with several foodborne pathogens in the field, during harvest or during postharvest handling. Sources of contamination could be from manure, sludge, and runoff water (Beuchat, 2006). High attention to hygiene is necessary from farm to fork.

2.4. Exposure to ethylene:

Exposure of green bean pods to ethylene during refrigerated storage can be detrimental since this plant hormone can initiate senescence. Ethylene concentrations of 0.17-1.17 µL per L cause rapid loss of chlorophyll (green pigments) and decreases shelf-life (Wills and Kim, 1996).

2.5. Chilling injury:

Chilling injury occurs if pods are stored below 5°C for 6-8 days. Symptoms of chilling injury are discolouration and rusty brown spots, while pitting on pod surfaces is less common (Cantwell, 2004). Symptoms begin to show after a day or two after removal from cold storage and increase rapidly if the green beans are held at ambient or typical marketing display temperatures.

2.6. Browning:

Pods with end-broken browning are due to increasing soluble phenolic content (Henderson et al., 1977). At the packinghouse, green beans are trimmed by cutting pods to uniform lengths, but this practice damages the beans and increases browning.

3. Postharvest chain of green beans

3.1. Harvest

Harvest time is important in determining the quality and shelf-life of green bean pods. Green bean pods are very perishable due to harvest at the immature stage, that is, before seed formation or at the beginning of seed formation (Costa et al., 1994). Green bean pods are harvested either mechanically or by hand (Figure 2).

Mechanical harvest is usually preferred for green beans intended for processing. The advantage of mechanical harvesting is the reduction of harvest cost; the main disadvantage is the reduction of quality. Most machines cannot select pods at the correct harvest stage, so usually, all pods are harvested regardless of maturity or condition. In addition, mechanical harvesting of green beans can cause physical damage to pods. About 25% of commercial yield could be lost due to mechanical harvest (Glancey et al., 1997).

Manual harvesting of green bean pods generally assures high-quality pods and good shelf-life. Harvest should be done in the early morning to avoid heat injury and after dew evaporates. This will reduce the incidence of fungal postharvest diseases. Use of harvesting containers with sharp edges must be avoided to reduce cuts, abrasions and bruising of pods. Labourers should remove rings, wash their hands or wear gloves to avoid pod contamination. The best method for harvesting pods from the plant is holding the plant by one hand and stripping the pods with the other hand. Harvesters can either use their thumbs to grasp pods or use sharp scissors.

Figure 2. Manual harvesting of green bean pods

The pods should be harvested with about 1 cm of stem. Hand harvest should be done gently to avoid damage to the pods and to the plants. Overhandling and rough handling of pods should be avoided to reduce visible and latent damage. All mature pods should be harvested, and immature pods should be allowed to remain for the next harvest. It is recommended to harvest all mature pods before moving to the next plant. Bean pods should be moved immediately to shade in the field until transfer to further processing. Green bean pods should not be exposed to direct sunlight to reduce pod temperature which reduces quality (Prusky, 2011).

3.2. Precooling

After harvest, green bean pods should be immediately cooled to eliminate field heat, reduce respiration, and reduce microbial growth, and shrivelling. The best precooling method is forced air cooling (Figure 3). This method could accelerate water loss due to cold air movement around pods (Sargent, 1995), so the cooling process should be monitored and managed to remove the crates of beans as soon as they reach the 7/8th cooling temperature. For example, if the desired temperature is 7 °C, and the initial temperature is 27 °C, the 7/8th cooling temperature is 10 °C.

Figure 3. Forced air cooling method

3.3. Sorting

Elimination of unacceptable pods (immature, overmatured, broken, and diseased) is necessary after harvest, to reduce the spread of postharvest diseases and enhance the quality grade (Figure 4). Tables or belted conveyors at the packing house could be used to help workers identify and remove unacceptable pods. Gentle handling is essential to prevent damage.

Figure 4. Sorting of green bean pods

3.4. Packing

Packing affects green bean pod quality. Weight loss and decay of pods are reduced by the selection of suitable packaging (Trail et al., 1992). Green beans are packed in several types of containers, depending on the demands of the market and consumer. The most common containers are fiberboard boxes and perforated polyethylene bags (Figure 5). Use of food grade polyethylene bags for green bean pods will help to reduce water loss, conserve total sugars, reduce chlorophyll degradation and vitamin C loss (Sistrunk et al., 1989; Watada et al., 1987). Polyethylene bags for packaging highly perishable crops work best under refrigerated conditions during shipping and storage.

Figure 5. Green beans packed in perforated polyethene bags and fiberboard boxes

3.5. Refrigerated storage

Storage temperature after harvest, and during handling, affects the quality of green bean pods including not only visual qualities such as colour, appearance and freshness but also the nutritional content of pods. The optimal refrigerated storage conditions for green bean pods are 5-7.5 °C and 95-100 % RH (Cantwell and Suslow, 2010). Under these conditions, pods could remain up to 12 days with an acceptable appearance. The maximum shelf-life of green bean pods is 4 weeks (Sánchez-Mata et al., 2003).

- Effect of storage temperature and period on weight loss:

  Weight loss of green bean pods can increase with increasing storage temperature (Guo et al., 2008). Green bean pods stored at 10°C or above, exhibit faster weight loss, yellowing, softening, shriveling, loss of total soluble solids, vitamin C and green pigments (chlorophyll a and b) than pods stored at a lower temperature (Proulx et al., 2010). Storage of green bean pods above 7.5 °C increases weight loss, decay, green pigment loss, and wilting (Zong et al., 1992). Storage studies have shown that the high weight loss obtained for beans stored at all temperatures suggests that the use of a film wrap may help create high relative humidity and therefore reduce water loss, maintain better overall quality, and extend the shelf life of snap beans (Proulx et al. (2010).

- Effect of storage temperature and period on vitamin C:

  Vitamin C (ascorbic acid) is usually used as an indicator for fresh vegetable quality including for green beans (Trail et al., 1992). Factors which enhance water loss from pods also cause increased loss of vitamin C (Lee and Kader, 2000). Vitamin C content of green bean pods decreases with increasing storage temperature (Howard et al., 1999) and with increasing time in storage (Wu et al., 1992).

- Effect of storage temperature and period on colour (chlorophyll content):

  Reduction of chlorophyll content in green bean pods is often related to increasing storage temperature and storage period. Green bean pods stored at 5 °C were greener than pods stored at 10 °C (Trail et al., 1992). Visual colour of green bean deteriorated during storage, regardless of the temperature, because the pods became less bright green, duller, and more yellow (Proulx et al. 2010). However, the color of green beans stored at 15 and 20 °C tended to deteriorate faster than that of pods stored at lower temperatures (Proulx et al. 2010).

- Effect of storage temperature and period on pH, acidity, and total soluble solids:

  The pH of green bean pods was 6.4 at harvest and this did not change due to storage period or temperature (Proulx, 2002). The acidity of green bean pods decreases with increasing storage duration (Proulx, 2002; Guo et al., 2008). Lower storage temperature usually conserves acidity of pods (Burzo et al., 1994). Snap beans stored at temperatures higher than 10 °C had lower acidity, soluble solids, ascorbic acid, and chlorophylls contents than those stored at lower temperatures (Proulx et al. 2010). Total soluble solids of green bean pods decrease with increasing storage period beginning with the first day of storage (Trail et al., 1992). During the last days of storage, increased total soluble solids can occur (Guo et al., 2008) when measured by weight, which is likely due to moisture loss.

- Effect of storage temperature and period on total sugar:

  Total sugar of green bean pods generally increases beginning with the first day of storage and decreases toward the end of storage. The decrease of total sugar at the end of the storage period could be due to the consumption of simple sugars during respiration (Sánchez-Mata et al., 2003).

- Effect of storage temperature and period on ß-carotene content:
  ß-carotene content of fresh cut green bean pods was about 2.9 mg per kg fresh weight at harvest according (Wu et al., 1992) and was not changed after refrigerated storage for 3 days at 4 °C plus 4 days at 10-16 °C.
- Effect of storage temperature and period on total protein content:
  The total protein content of green bean pods was about 16.4 g per kg wet weight at harvest (Sánchez-Mata et al., 2003) and not changed during refrigerated storage at 8 °C for 22 days in normal air or under controlled atmosphere conditions (3 % O_2 + 3 % CO_2).

3.6. Transportation

The type of transport is important can affect the quality of green bean pods due to their high water content and short shelf-life. Transport from the field to packinghouse is the first step which takes place usually by manual hauling. This process should be done as soon as possible after harvest to reduce water loss and respiration rate. The quality of refrigerated transport, distance between the farm and the market, and road quality are factors which determine the level of loss occurring during transport.

4. Postharvest treatments for increasing storability

4.1. Ozone

Ozone is an effective disinfectant which affects gram-negative and gram-positive bacteria, spores, vegetative cells, and fungi (Horvitz and Cantalejo, 2014). Green bean pods treated with 40 ppm ozone for 1 hour had reduced total bacterial counts (Qiang et al., 2005) during storage.

Editorial note: 40 ppm ozone gas is very high for human to handle. Exposure to even 0.3 ppm ozone can cause lung inflammation and cardiovascular malfunction (Devlin et al. 2012). WHO permits handling 0.06 ppm ozone (Bocci, 2011), while US OSHA and UK HSE permits up to 0.1 ppm at work place during 8 h day work (HSE, 1996).

4.2. UV-C irradiation

Use of UV-C irradiation can retard postharvest senescence and minimize decay of vegetables (Allende and Artès, 2003; Severino et al., 2014). Firmness loss and colour loss of green bean pods decreased due to UV-C treatment.

4.3. γ-Irradiation

Use of γ-irradiation may be useful in reducing microbial growth and extending shelf-life of vegetables (Turgis et al., 2009). Green bean pods treated with γ-irradiation and stored at 4°C for 12 days had reduced growth of *Listeria innocua* (Severino et al., 2014) and *Escherichia coli* O157: H7 and *Salmonella typhimurium* (Severino et al., 2015) compared to controls.

4.4. Essential oils

Essential oils may have promise as an antimicrobial agent that could be used to control foodborne pathogenic bacteria and some plant pathogens (El-Mogy and Alsanius, 2012). Nanoemulsion of mandarin orange (*Citrus reticulata*, Clementine) essential oil using a modified chitosan coating containing 0.05% oil reduced *Listeria innocua* growth on green bean pods (Severino et al., 2014; Donsì et al., 2015). Carvacrol nanoemulsion oil was effective for controlling *Escherichia coli* O157: H7 and *Salmonella typhimurium* on green bean pods (Severino et al., 2015).

4.5. Controlled atmosphere (CA) storage and modified atmosphere packaging (MAP)

Deterioration of fresh vegetables in storage could be minimized using controlled atmosphere storage. Introduction of external O_2 and CO_2 levels around the fresh product reduce O2 level and increase CO_2 from normal air composition which could increase shelf-life and maintain the quality of the fresh product. By decreasing O_2 level and increasing CO_2 level, respiration rate is reduced due to decreased polyphenol oxidase, ascorbate-oxidase and glycolic-oxidase enzymes activity (Kader, 1986), senescence, softening, and loss of chemical constituents of vegetables can be delayed. Green bean pods stored in 3% O_2 + 3% CO_2 controlled atmosphere exhibited the best shelf-life and minimum loss of nutrients (Sánchez-Mata et al., 2003).

Bioactive chitosan-based nanoemulsions or gamma irradiation treatment (described above) have been shown to control the growth of *Escherichia coli* O157: H7 and *Salmonella typhimurium* during the entire storage period. Moreover, it was also found that the combined treatment of antimicrobial coating, gamma irradiation and MAP caused the reduction of microbial population to undetectable levels during the whole storage period for E. coli and from day 7 to the end of storage for *Salmonella typhimurium* (Severino et al., 2015).

4.6. Calcium chloride treatment

Calcium plays an important role in the preservation of cell wall integrity of fresh vegetables by combining with pectin in the middle lamella to protect from loss of firmness. Calcium combines with pectin to create calcium pectate. Fresh cut green bean pods retained good quality by immersing them in calcium chloride, where calcium chloride treatments (green beans dipped in 0.5 to 3% aqueous solution calcium chloride for 90 seconds) on green beans retained the quality for the first 4 days of storage compared to the control group (Kasim and Kasim, 2015).

5. Conclusions and recommendations

Green beans must be harvested at the proper maturity, handled gently and rapidly during packing, protected from the sun and rough surfaces, and precooled as soon as possible after harvest. If green beans are refrigerated during shipping or storage it is important to avoid chilling temperatures. By using best postharvest handling practices, cooling and simple treatments to prevent deterioration and packaging to slow water loss, green beans can be successfully stored at 7 °C and 95% RH for 2 to 3 weeks.

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