AHDB

Outdoor cucurbits storage review

HORTICULTURE

Contents

The information in this booklet was compiled by Debbie Rees, Aurélie Bechoff, Marcin Glowacz and Richard Colgan, Natural Resources Institute, University of Greenwich.

Photographic credits

Introduction

The Cucurbitaceae family include a wide range of crops, namely 126 plant genera and 3,801 species). This publication reviews information on the best practices for the storage of cucurbit crops grown outdoors in the UK: courgettes and marrows (*Cucurbita pepo*), butternut squash (*Cucurbita moschata*) and pumpkins (*Cucurbita maxima*). It also examines gaps in knowledge and provides recommendations for areas of research for these specific crops. Given the profile of outdoor cucurbit crops grown in the UK, and the information available, the review focuses mainly on courgette and pumpkin.

Specific issues covered in this review include the impact of the following factors on the storage of outdoor cucurbits:

- Variety
- Agronomic practice
- Dry matter content of fruit
- Time of pick; hydration levels
- Washing practice (it also reviews alternatives to washing)
- Disease and defect impacts on storability and how these can be avoided

The review focuses on outdoor cucurbit crops of economic importance to the UK. Courgette crops are the most economically important, at £29m, followed by pumpkin, which was valued at £14–15m in 2017.

The courgette (also known as zucchini or summer squash) and the marrow are both fruits of the species *Cucurbita pepo*, but the courgette is harvested at a less mature stage than the marrow. Several types of squash are grown in the UK – the most commonly grown is the butternut squash, which is the fruit of *Cucurbita moschata*. The pumpkin is the fruit of the species *Cucurbita maxima*. Butternut squash, pumpkin and marrow are sometimes referred to as 'winter squashes'.

In terms of keeping potential, courgettes are immature fruit and are, therefore, more perishable than winter squash, such as pumpkins, marrow and butternut squash, which are harvested when the fruit is mature. However, in the UK, losses in storage are high for pumpkins where planting is scheduled for the crop to be ready for harvest for the Halloween market (31 October). There is, therefore, a lack of storage facilities with environmental control for pumpkins.

Diseases also affect the storage potential of outdoor cucurbits. For courgette, fruit disease issues highlighted by UK growers include powdery mildew, gummosis (scab), caused by *Cladosporium cucumerinum*, viruses and *Botrytis* as well as *Fusarium*, *Phytophthora*, *Pythium*, *Sclerotinia*, and *Verticillium*. Deterioration in quality due to water loss is also particularly important for courgettes.

Until recently, there was little information on the main rotting pathogens for pumpkins in the UK. However, a survey of rots carried out in 2014 and 2015 in the AHDB Horticulture project FV 439 '***Cucurbits: Identifying pre-harvest, harvest and post-harvest management practices capable of reducing losses of pumpkins during storage***', identified the main cause of postharvest losses to be *Phoma cucurbitacearum*. As a result, fungicide and nutrition spray trials were carried out to develop in-field management strategies, to reduce the risk of postharvest storage losses due to this rot pathogen.

This review also provides information on the recommended storage conditions and reported storage life of a range of different cucurbits, ranging from 1–2 weeks for courgette, and up to several months for the tougher-skinned squashes. For courgette, which is the higher value crop to pumpkins in the UK, investment in controlled storage environments may be warranted.

Market status of UK outdoor cucurbits

Courgettes

Of the cucurbits considered in this review, courgettes are the most important economically. The demand for courgettes in the UK is increasing, as illustrated by an 8-fold increase in imports over the past 30 years (Figure 1). The UK currently imports courgettes from Southern Europe, especially Spain and Southern France by road freight **fw.co.uk** (2017). This supply is obviously sensitive to climatic events, as illustrated by the shortages in early 2017, which were due to cold weather. UK courgette production has also increased, presumably in response to demand (£19m in 2016 to £29m in 2017, Defra Horticultural Statistics, 2017). There is also an export trade for UK courgettes, which is small but increasing (£0.5m by 2017). Given the growth in this market, there is a need to optimise the postharvest handling chain for this delicate crop, both by considering handling strategies, and the preharvest and harvest practices that impact on courgette postharvest quality.

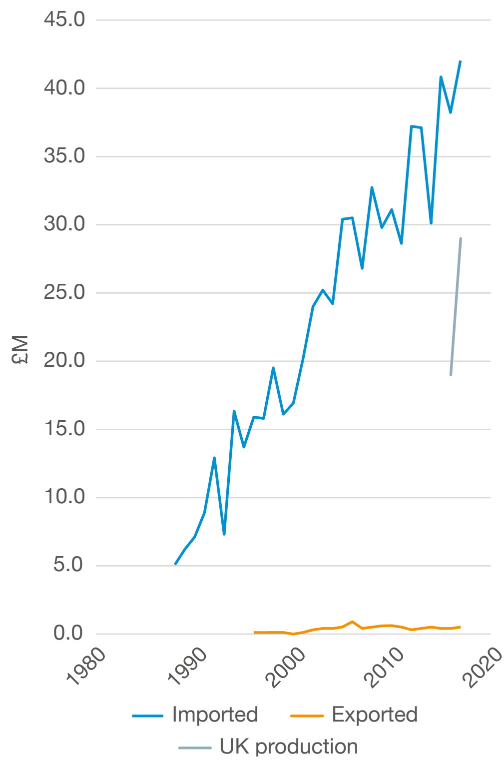

Figure 1. UK Courgette production, export, and imports to the UK Defra Statistics 2017

Courgettes are fast maturing: they have soft rinds and are consumed when the fruit is immature. They can be stored for a few weeks. Fruit may be harvested at an immature stage, at the desired fruit size, before seeds begin to enlarge and harden. A thin, soft external rind and glossiness are indicators of a premature condition. The entire fruit is edible, either raw or cooked, without the removal of seeds and the seed cavity tissue.

Small, young fruit are tender and generally have a slightly sweet taste. Courgettes are selected for their tenderness and their characteristic epidermal green stem colour. Very immature fruits, such as baby courgettes, and the edible blooms of the courgette plant, are in high demand by upmarket restaurants, commanding high prices. When conditions for growth are good, the time from flowering to harvest may take only 45–60 days. In warm weather, courgette fruits are harvested daily or every other day. The rind becomes dull as the courgette becomes over-mature with a concomitant loss of quality. For best eating quality, courgette should be consumed soon after harvest.

Pumpkins

The market for carving pumpkins in the UK was estimated at £14–15m in 2017 and is considered to be growing at a rate of 20% annually. Losses during storage were estimated to be 15–20% in 2014, equating to an annual loss of £2–3m for carving pumpkins alone. The challenges for postharvest handling are unusual for this crop, given that the demand is almost completely focused on Halloween, regardless of the timing of crop maturation. Furthermore, the economics of the pumpkin market do not allow farmers to invest in storage structures. In the UK, storage is currently in uncovered windrows in the field and within greenhouses, or in bins within stores (usually without refrigeration). Usually, no specific temperature or humidity control is used, but, in some cases, there is forced airflow to reduce the build-up of condensation. No ventilation within windrows is used.

The market for squash, primarily butternut squash, is lower than that for pumpkin but it is increasing. Likewise, there is an increasing market for culinary pumpkins.

Winter squashes (pumpkin, marrow and butternut squash) are harvested upon reaching physiological maturity when seeds are fully developed or during ripening when the fruit has reached the required level of market quality. They develop durable rinds and they have a longer growing season, taking 80 to 110 days to mature, depending on weather and cultivar. They also have a relatively longer storage life, potentially of several months.

Outdoor cucurbit contribution to the human diet

As the market for culinary squashes and pumpkins increases, their nutritional value could be an important criterion for varietal choice in the future. Orange-fleshed winter squashes (such as pumpkin and butternut squash) provide an excellent source of vitamin A. Two compact tropical pumpkin hybrids (*Cucurbita moschata*) were recently released and reported to contain 49 mg/kg and 57 mg/kg fresh mass total carotenoids in the pulp, respectively, higher than that reported for butternut squash (45 mg/kg FM) (Maynard et al. 2002).

UK Outdoor Cucurbit Growers' Group research priorities

At the time this report was updated (2019), the priorities relating to harvest and postharvest handling of cucurbit identified by AHDB and the Outdoor Cucurbit Growers' Group (OCGG) were as follows (Table 1):

Table 1. OCGG Harvest and postharvest research priority areas

Priority area		Current or recent research	Priority rating
Postharvest management	Time of pick, cooling Cleaning, washing, and impacts on shelf life and skin shine; options for cleaning Hydration Extending varietal storage potential Investigate dry matter/storage potential correlation Causes of pitting in storage	FV 439: Cucurbits: Identifying preharvest, harvest, and postharvest management practices	High
Storage	Optimise storage conditions for cucurbits Use of ethylene in controlled atmosphere storage	New technologies in FV 395 for broccoli. CP 83 strategies to minimise radish splitting. TF 200 looking at novel products/ optimising SmartFresh technology TF 201, etc.	High
Technology	Scanning/image analysis Precision spray application		
Improving product quality	Pollination for fruit quality Support pollinating insects Need self-pollinating varieties	Defra HortLink project HL0192: Perennial field margins with combined agronomical and ecological benefits for vegetable rotation schemes – CP 118 Cucurbit Pollination studentship	High

Quality considerations

Courgette

Courgette quality is based on uniform shape, tenderness of rind and internal tissue, an overall firmness, glossy skin colour, and an intact well-trimmed stem portion. Uniformity of shape (i.e. free of twisting, groves, or other disproportionate growth defects) is also an important quality factor and is defined as a characteristic of the variety. Additional quality indices include a lack of growth or handling defects (discolouration, cuts, bruises, abrasions, pitting), freedom from decay, and an absence of yellowing on dark green varieties. Given that courgettes are prone to physical damage, having a good handling process is central to good quality. Size is also an important consideration for the various markets.

At present, breeders are focusing on resistance to disease, but also retention of surface shine.

For dark green varieties, retention of chlorophyll is key, but white and yellow varieties have also been introduced. Although good taste is an important criterion, there is little information available on courgette tasting quality and on whether or not taste is considered or incorporated into breeding programmes.

Pumpkin and other winter squash

For pumpkin and winter squash with tough skins, surface damage is less of an issue. Important quality characteristics are the size, shape, colour, and intactness of stem. For pumpkins, development of an orange colour can be the issue. For culinary pumpkins and squashes, internal quality attributes are a good orange colour, which is due to a high carotenoid content, and high dry weights, sugar and starch contents. As consumer demand for nutritious food increases, it is likely that nutritional values will become a more important quality criterion.

Recommended storage conditions

Table 2 summarises information on the recommended storage conditions and reported storage life of a range of cucurbits. This ranges from 1–2 weeks for courgette and up to several months for the tougher skinned squashes. These reported storage times depend on the maintenance of the recommended storage environment, and are, therefore, dependent on the resources available for storage. In the case of a high-value crop such as courgette, investment in controlled storage environments should be considered, as it is economically feasible; whereas, for pumpkin, as described in Section 1, stores or storage structures are not usually available.

The storage potential for a range of winter squashes is included in Table 3. This illustrates the variation that exists between varieties.

Table 2. Summary of storage conditions for cucurbits found in literature

Cucurbit	Storage conditions*	Reference
Courgette	1–2 weeks under ideal conditions 5–10°C, 95% RH	Midwest Vegetable Production Guide for Commercial Growers 2013 (ID-56) **hort.purdue.edu/prod_quality/commodities/zucchini.html#top**
	11 days; 7–8°C	Jacobi et al. 1996
Squash	1–6 months; 10–13°C; 50–70% relative humidity (RH)	N.S. Mansour, Extension vegetable crops specialist, Oregon State University 2009 **ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/12889/ec1632.pdf;jsessionid=0D9887694FCF3D7E4735C2D862C637F5?sequence=1**
	4–11 weeks; 10–15°C; 50–70% RH	Cornell University Department of Plant Pathology **vegetablemdonline.ppath.cornell.edu/factsheets/Cucurbit_FrtRots.htm**
Pumpkin	2–3 months; 10–13°C; 50–70% RH	N.S. Mansour, Extension vegetable crops specialist, Oregon State University 2009 **ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/12889/ec1632.pdf;jsessionid=0D9887694FCF3D7E4735C2D862C637F5?sequence=1**
	<3 months; 10–13°C; 50–70% RH	Mark Gaskell University of California Cooperation Extension Pumpkin Production in California. Publication 7222, 1–4
	8–12 weeks; 10–13°C; 50–70% RH	Cornell University Department of Plant Pathology **vegetablemdonline.ppath.cornell.edu/factsheets/Cucurbit_FrtRots.htm**

*Storage times are dependent on variety

Table 3. Summary of storage conditions/potential for a range of winter squash

Culinary type	Temperature (°C)	Percent relative humidity	Storage life expectancy
Acorn	15–20	60	4 weeks
Acorn	10–15	60	4–7 weeks
Buttercup	10	50–70	13 weeks
Butternut	10–15	60–70	7 weeks
Butternut	10	60–70	8–11 weeks*
Hubbard	10–15	60–70	27 weeks
Turban	10	50–70	13 weeks

*Storage for 4 months or more is possible if all production, curing, and storage recommendations are followed (Cornell University Department of Plant Pathology)

Cucurbit physiological impacts on storage

To determine optimum storage protocols and conditions, it is important to understand the products' physiological processes. Rates of respiration at different temperatures, as measured by production of carbon dioxide (CO_2) production and rates of ethylene production for the different types of cucurbits, are given in Table 4 and covered below.

The quoted rate of ethylene production for courgette at 20°C (68°F) is 0.1–1.0μl/kg per hr.

The optimum storage conditions for courgette have been determined as a temperature of 5–10°C (41–50°F) and 95% Relative Humidity (RH). Under these conditions, courgettes are reported as keeping for 10 days in good quality.

For pumpkin and other winter squashes, the rates of respiration are reported as 30–60 ml CO_2/kg hr at 25°C (77°F), with rates of ethylene production being <0.5 μL C_2H_4/kg hr at 20°C (3–5 times increased when exposed to chilling conditions).

The optimum storage conditions for pumpkin and winter squashes have been determined as a temperature of 12.5–15°C (55–59°F) and 50–70% RH, with 60% being considered as optimal. Under such conditions, pumpkin and winter squashes store for between 2–3 months.

Table 4. Rates of respiration: courgette

Temperature	0°C (32°F)	5°C (41°F)	10°C (50°F)	15°C (59°F)	20°C (68°F)
ml CO_2/kg·hr1	6–7	7–10	17–18	37–45	42–4

To calculate heat production, multiply ml CO_2/kg hr by 440 to get Btu/ton/day or by 122 to get kcal/metric ton/day.

Source: University of California Davis Product Factsheets, 2019

Storage losses and their causes

Many factors impact on cucurbit storage potential. These include physiological age at harvest, preharvest, harvest and postharvest fruit injury, exposure to chilling or freezing conditions or ethylene, water loss and the preharvest disease load in or on the fruit surface, which may lead to postharvest rots or fruit discolouration and distortions.

Physiological deterioration

As for other fruits and vegetables, cucurbits continue to be physiologically active after harvest and will start to deteriorate as the tissues change, through the natural development of the product. All fruits progress through a stage of senescence (programmed cell death) after reaching full ripeness and, even for immature fruit such as courgettes, this same process will occur following harvest. Senescence is characterised by tissue softening due to cell wall changes, loss of cellular integrity, breakdown of chlorophyll (loss of green colour), breakdown of external waxes, changes in metabolite concentrations (in this case, conversion of sugars to starches and loss of acids), decreased production of aroma volatiles and eventually development of off-flavours due to fermentation. Storage environments are designed to slow down this physiological ageing process. In the case of courgettes, the main strategy is to use low temperatures to slow metabolism. However, in the UK, pumpkins are mostly stored outside under ambient conditions.

As senescence is a natural physiological process, it is controlled by the natural production of plant hormones. Ethylene is one such plant hormone. Control of ethylene in the storage environment is a strategy to reduce deterioration rate during storage.

Physical injury

Physical damage will increase rates of deterioration by increasing water loss and allowing entry of rotting pathogens. In addition, damage increases the rate of ethylene production and therefore rates of senescence. Of the four focus commodities, soft-skinned courgettes are particularly sensitive to damage. Bruising, scuffing, and compression injury are common when attention to careful harvest and gentle handling practices are not followed; this speeds up deterioration.

After harvest, stem damage caused by harvesting and the scar left by flower abscission are both important routes of infection. To reduce the effect of stem damage of courgettes, harvesting should be done by cutting free of the vine rather than by snapping. A poorly trimmed stem end is a quality defect and, as it contains more damaged cells than a clean-cut, it promotes decay. The flower abscission scar (Figure 2) can be large and may provide a site of postharvest rot development, especially if wet weather coincides with flowering, or if flower abscission is late and healing of the wound incomplete. Flower abscission is controlled by the natural hormone ethylene. In the situation where late flower abscission is a problem, ethylene treatment in the field might provide a possible solution (Payan et al 2006).

Figure 2. The blossom end scar formed by flower abscission on a courgette

Although tougher skinned pumpkins and squashes are less prone to injury, a common form of injury observed during project FV 439 was puncturing by stems of neighbouring fruit, which then provided a route for infection, for example, by *Phoma*.

Chilling injury

Although, as mentioned above, low-temperature storage is an important strategy to extend storage life, the optimum temperature should be chosen carefully, as cucurbits are susceptible to chilling injury, which occurs when the crop is exposed to temperatures below the safe storage temperatures (although exposure temperatures are above 0^{0}C, or freezing). This can occur in the field, but most commonly happens during handling and transport, and is a particular risk in situations where the temperature control is not uniform (for example, near the chiller in a freight container). Chilling injury is time-temperature related (i.e. it increases with the time in which the produce is stored below the safe temperature). It is caused primarily by a disruption in normal functions in cell membranes, leading to localised cell death (termed necrosis). Once the integrity of the tissue is compromised, infection readily takes place by saprophytic microorganisms. External symptoms of chilling injury in cucurbits include the appearance of pitting and water-soaked or sunken areas. In many cases, symptoms become worse once the commodity has been moved to a higher temperature. This aspect of chilling injury makes it a particular problem for handlers of fresh produce, as the symptoms may not appear until the produce is with the retailer.

Courgettes can be stored at 5°C with acceptable market quality for up to two weeks. However, storage below 5°C for more than 3–4 days will generally result in chilling injury. Visual and sensory quality deteriorates, and surface pitting and discolouration or browning progress rapidly following chilling injury (Figure 3). Shrivelling, yellowing and decay are likely to increase following storage beyond two weeks, especially upon removal to typical retail conditions. Courgette varieties have been observed to differ in susceptibility to chilling injury, although the authors of this publication were unable to find specific information on UK varieties. In many commodities, modification of the storage atmosphere can reduce symptoms. See the **Modified and controlled atmosphere storage** section.

Figure 3. Pitting in courgette due to chilling injury

Pumpkins and winter squash are chilling-sensitive when stored below 10°C. Symptoms of chilling injury are sunken pits on the surface and high levels of decay, once fruits are removed from storage. Research at Oregon State University showed that, for eight currently produced winter squash cultivars stored at 10–15°C, 90%, 70%, and 50% were marketable after 9, 15 and 20 weeks, respectively (Suslow & Cantwell 2013). Choosing the optimum storage temperature often requires a compromise to find temperatures low enough to slow down physiological development leading to senescence, but not so low as to cause chilling damage.

For green rind squashes, storing at the higher temperature of 15°C may cause degreening, undesirable yellowing, and texture loss. The green rind squashes can be stored at 10–12°C to prevent degreening, although some chilling injury may occur at the lower temperature. High storage temperature (>15°C) will result in excessive weight loss, colour loss and poor eating quality. As for courgette, the susceptibility to chilling injury in winter squashes is cultivar-dependent (Suslow & Cantwell 2013), but there is no specific information on UK cultivars. In practice, in the UK, for carving pumpkins, short exposure to temperatures lower than 10°C is unlikely to cause damage of economic importance. However, chilling injury may become a significant factor for the eating quality of culinary pumpkins, due to the potentially longer storage periods. Therefore, the challenge to extend the season for culinary pumpkins beyond November will require more sophisticated storage technology.

Freezing injury

Freezing injury occurs when temperatures drop below 0°C in the field or during shipping and handling. It is distinguished from chilling injury in that frozen tissues appear necrotic, water-soaked and flaccid, generally covering larger areas of the fruit surface and extending into the flesh, depending upon severity. The formation of inter-cellular ice is the main cause of freezing injury (Kays 1991). Freezing injury can occur during shipping in refrigerated trailers that have top air delivery. In these systems, refrigerated air is blown to the rear of the trailer via a ceiling duct (or 'air chute'). Often, the outlet air temperature is below freezing, causing fruit loaded directly under the air outlet to freeze or suffer chilling injury during transit.

As it is often associated with poor temperature distribution within containers, the occurrence of freezing injury is essentially an indication of a management problem in the supply chain. Solutions to this problem would include improving packaging arrangements, or, in extreme cases, a redesign of the container itself.

Exposure to ethylene

Exposure to ethylene gas during storage or transport can accelerate senescent processes in cucurbits. For example, premature chlorophyll degradation is induced in courgettes and other green-coloured squash. Ethylene will also cause the abscission of the stem, especially in less mature fruit. As ethylene promotes abscission, it could be an ideal way of speeding up the detachment of the courgette flower. Careless handling significantly reduces postharvest life because damaged tissues produce ethylene as part of the wound response, leading to an increase in rate of senescent processes.

Courgette varieties are low to moderately sensitive to exogenous ethylene compared with other perishable commodities. Pumpkins and winter squash produce only trace amounts of ethylene, but wounding greatly increases ethylene production (Hyodo et al. 1993). In the US, it is recommended that dark green-skinned squashes should not be stored near apples, as the ethylene from apples may cause the skin to turn orange-yellow (Yeager et al. 1945).

Water loss

Water loss is an important cause of deterioration for fruits and vegetables. As well as being a direct cause of quality loss, because of visible shrivel and loss of texture, the stress of desiccation has a direct effect on the ability of plant tissues to resist rotting pathogens. Excessive weight loss during postharvest handling leads to fruit softening and increases susceptibility to mechanical injuries, another factor that increases infection by disease pathogens. This is particularly important for courgettes.

Immature-harvested fruits, such as courgettes, are more susceptible to water loss during postharvest handling than those harvested mature, as they generally have a thin epidermis and partially formed epicuticular wax, making them more susceptible to loss of water through surface tissues. They also tend to have higher moisture content in the edible portion than mature fruits. Open pores (lenticels), stem-end and blossom-end scars are primary points of water loss and gas exchange and shrivel symptoms generally first appear at the stem-end, which has the highest gas exchange rate, including transpiration of water (Sargent & Maynard 2012). When produce is cooled, the careful control of the rate of cooling is critical for reducing water loss. Water loss can generally be reduced if the produce is cooled promptly and rapidly (Sargent & Maynard 2012).

Postharvest rots

Diseases are an important source of postharvest loss across all fresh produce, although it should be borne in mind that the extent of rotting and, therefore, losses are not only determined by the presence of the rotting pathogen but are strongly influenced by other factors such as variety, storage temperature, and humidity conditions. Physical injuries on the fruit provide entry points for rotting pathogens to enter. Stresses such as chilling or freezing injury can reduce the natural resistance of produce against the pathogens. There is a wide range of bacterial and fungal pathogens that can cause postharvest losses in transit, storage, retail and consumer homes.

Postharvest rots of courgettes

Fruit disease issues highlighted for courgette by UK growers include powdery mildew, gummosis (scab), caused by *Cladosporium cucumerinum*, viruses and *Botrytis* as well as *Fusarium Phytophthora*; *Pythium Sclerotinia* and *Verticillium*. It is assumed that fruit is infected during growth.

Field hygiene and disease control programmes reduce the levels of fungal spores and bacteria available in the crop preharvest and at harvest. However, a major factor affecting the levels of infection is the susceptibility of the cucurbit variety to rot development (rather than, for example, levels of fungal spores present). Unhealed wounds provide entry points for pathogens. The persistence of the courgette flower in some seasons has been associated with an increase in the incidence of gummosis by UK growers. The health of the commodity is an important factor in development and progression of the rot. It is possible that a consideration of mineral nutrition could have an impact on the development of rots.

Postharvest rots of pumpkin

Management of cucurbit rots is a particular challenge, as fruits tend to be in contact with the soil. Where spraying is possible, dense canopies can prevent coverage of the fruit. Most of the fruit-rot-causing pathogens also survive in the soil for a long time.

Until recently, there was little information on the main rotting pathogens for pumpkins in the UK. However, a survey of rots carried out in 2014 and 2015 (AHDB project FV 439), identified the main cause of postharvest loss to be *Phoma cucurbitacearum* (Figure 4). As a result, field trials were set up, with the aim to reduce the postharvest incidence of this rot. The trials focused on nutrition and approved fungicides.

It was notable during the assessment of storage rots within project FV 439, that there was little evidence that rots spread between pumpkins during storage. It appeared that the pathogen could not

Figure 4. Rotting of stored pumpkins due to *Phoma cucurbitacearum*

penetrate the skin of the pumpkin unless there was a puncture. Details of project FV 439 trials and findings are outlined in the AHDB Horticulture '***Crop management strategies to improve pumpkin storage***' 2019 factsheet.

Postharvest rots of other squashes

The extension services in the US are a good source of information on the rots of winter squashes other than pumpkin, such as butternut squash, although there is little information available on the relative incidence of these pathogens in the UK. In the US, several fungi are associated with decay during storage of winter squashes, including *Fusarium*, *Pythium*, and anthracnose (*Colletotrichum*) and gummy stem blight or black rot (*Didymella*). It is reported that Alternaria rot will develop on chill-damaged winter squashes, see **postharvest.ucdavis.edu/Commodity_Resources/Fact_Sheets/Datastores/Vegetables_English/?uid=28&ds=799**

It is reported that, in the UK, fruits harvested late (>2 weeks beyond optimal harvest date) are more susceptible to storage rots and that *Rhizopus* is a particular problem for fruit with physical damage.

Figure 5. *Fusarium mycelium* (fungal threads)

The impact of viruses on postharvest quality

Viruses are not considered a major problem for cucurbit growers in the UK but are known to reduce yields, cause premature plant death and result in fruit distortion. The main cucurbit virus in the UK is cucumber mosaic virus (CMV). However, since the end of the 1980s, the potentially more serious zucchini yellow mosaic virus (ZYMV) has become more prevalent in the UK. Control methods include control of aphid vectors and removal of alternative hosts among weeds. Virus-resistant varieties of courgettes and marrows are being developed.

Figure 6. Cucumber mosaic virus

Varietal impacts on storage

Courgette

A range of green courgette varieties are grown in the UK. Varieties grown in 2013 included El Greco, Tendor, Acceste, Tiger cross, Tosca, Mikonos, Milos, Cora, and Optima. However, seed companies continue to introduce new varieties, with postharvest quality retention traits such as surface shine being selected for. There are several studies in scientific literature that suggest variability among courgette varieties for storage potential, notably in terms of susceptibility to chilling injury.

Carvajal et al. (2011) studied the behaviour of a range of varieties of courgette during cold storage. Although this study was on Spanish rather than UK cultivars, the observation of varietal variation suggests the same is likely to be true of UK varieties. The varieties included in this study were 'Capea' (Clause-Tezier), 'Cónsul' (Seminis), 'Milenio' (Semillas Fitó), 'Natura' (Enza Zaden) and 'Sinatra' (Clause-Tezier).

In another study in California, the relative susceptibility of courgettes (green, yellow, crookneck and scalloped) to chilling injury was assessed (Table 5). Squash were harvested in June 1997 from a variety trial (established at Kearney Research Center in Parlier, California, by Cooperative Extension Advisors Manuel Jimenez and Richard Molinar) and stored for 10 days at 5°C (41°F) to evaluate the visual quality and chilling symptoms.

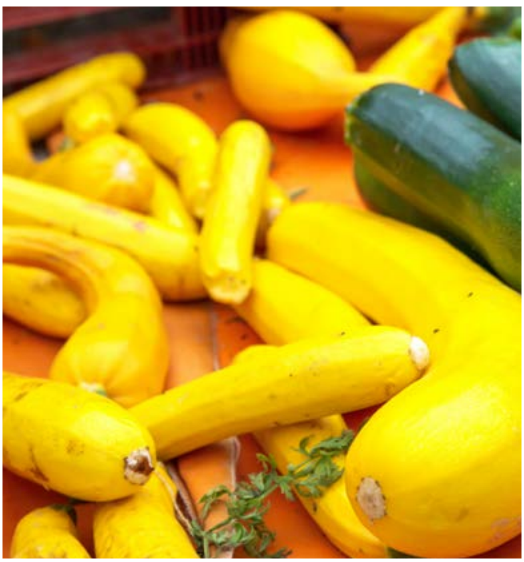

Table 5. Chilling susceptibility for key courgette varieties grown in California

Low	Intermediate	High
Supersett, Tigress, Starship, El Greco, Prelude, Gentry, Gemma,BN 95044, BN 95055, Golden Gate, ZS-11	Multipid, Butter scallop, Debutant, Picasso, Rivera, General Patton, Enterprise, Supreme, Counselor, Excel	Meigs, Senator, HMX 6704, Golden Rod, Superpik, Elite, Sunburst, Monet, Fortune Golden Dwan III, Revenue, ZS-5

Source: Department of Plant Sciences, University of California, Davis Trevor V. Suslow and Marita Cantwell

Pumpkin and winter squash

In the US, it is well known that the length of storage life varies according to variety and type of winter squash or pumpkin; ranging from 1–3 months for Table Queen (acorn type) and butternut squash, to 4-6 months for Hubbard, Buttercup (turban type) and Sweet Meat. Where the varieties differ in shape, colour and culinary characteristics, consumer acceptability will be at least as important as storage potential in choice of variety. However, in some cases, storage potential will be the key factor.

During project FV 439, a range of carving and culinary pumpkin varieties were characterised for quality characteristics and keeping qualities. There was a clear range of storage potential. Although results were not conclusive, within specific size ranges, high dry matter content tended to relate to improved storability. Currently, the three main UK carving varieties are Mars, Racer and Harvest Moon. Mars is a variety with higher flesh content and longer storage potential than similar-sized pumpkins with thinner flesh (pericarp). However, it has also been observed that varieties have various relative performances in different growing regions, both in terms of yield and keeping quality.

Again, the pattern of storage performance appears to relate to dry matter content; thus, Racer is considered a good storing variety in Hampshire in the UK, compared with Mars and Harvest Moon, but it is considered a bad storer in Cambridgeshire. This distinction is also seen in the comparison of dry matter content; Racer had the highest dry matter content of these three varieties in Hampshire, but the lowest in Cambridgeshire.

Preharvest chemical treatments to control postharvest rots

During project FV 439, *Phoma* was identified as a major rotting pathogen of stored pumpkin in the UK. In the US, where pumpkin is an important crop, powdery mildew control in the field is considered necessary to ensure healthy pumpkins for store. Therefore, in the AHDB project, a fungicide spray programme against both Phoma and mildew, with mineral nutrition was tested for efficacy and economic value at two UK sites in 2016, for the pumpkin variety Harvest Moon.

The programme relied on the use of Signum (Boscalid/pyraclostrobin), and Nimrod (Bupirimate). Signum is known to work against both powdery and downy mildew, as well as Cladosporium species and it was expected to be active against Phoma. Nimrod was known to have activity against powdery mildew. Mineral nutrition focused on calcium, boron, manganese, copper and magnesium sulphate. The field treatments used are summarised in Table 6. The treatments led to an increase in yield in terms of both the number and size of pumpkins and a significant reduction in postharvest rotting.

Nutrient feeding regime impacts on postharvest quality

Nutritional deficiencies during growth and development can lead to many disorders in cucurbits. In particular, nitrogen deficiency in the plant causes poor chlorophyll synthesis in fruits such as courgette, prized for its intense green epidermis. Nitrogen deficiency also decreases fruit size, but it increases dry matter content, causing the fruit to have a coarse or tough texture (Locascio et al. 1984).

Table 6. Applications of fungicide and nutrition used in a field trial in AHDB project FV 439

Site	Date	Fungicide	Nutrition
Cambridgeshire	27/7/2016	Signum (1.5 L/ha)	Calcium 1 L/ha, Boron 1 L/ha
	8/8/2016	Nimrod (600 ml/ha)	Calcium 1 L/ha, Copper Oxychloride 2 L/ha, Manganese (as per label)
	18/8/2016	Signum (1.5 L/ha)	Calcium 1 L/ha, Manganese (as per label)
Kent	18/7/2016	Signum (1.5 L/ha)	Calcium 1 L/ha, Boron 1 L/ha
	5/8/2016	Nimrod (600 ml/ha	Calcium 1 lLha, full trace elements foliar feed
	20/8/2016	Pot Bicarb (5 L/ha) + silica wetting	Calcium 1 L/ha, Manganese (as per label), Bittersalts (magnesium sulphate) as per label

As for many fruits, calcium is central to the postharvest quality of cucurbits. It plays a key role in maintaining plasma membrane integrity, thus slowing disruption of cellular functions that can occur during storage (Lester et al. 1998; Lester & Grusak 2001). It has an important role in cell wall structure: high calcium content usually leads to better maintenance of firmness. Severe calcium deficiency appears as water-soaked lesions at the blossom end of the fruit that later become necrotic (blossom-end rot); carpel separation from mesocarp tissue that forms air cavities at the stem end has also been observed (Frost & Kretchman 1989).

Calcium is also implicated in improved resistance to rots and, in fact, several minerals can have a significant impact on susceptibility to postharvest rots. Specific minerals can affect the ability of the tissues to defend themselves against infection by mechanisms such as the formation of mechanical barriers and synthesis of defence compounds (phytoalexins, antioxidants, and flavonoids). They can also have a direct effect on the ease with which rotting pathogens can invade the tissues. Where cell walls are weak, nutrients may leak from the cells into the intercellular spaces (apoplast), creating a favourable environment for germination of fungal spores.

Potassium (K) is essential for the synthesis of proteins, starch, and cellulose. Cellulose is an important component of the cell wall; K deficiency makes cell walls leaky. Calcium and Boron (B) are both components of the cell wall, so a deficiency in either increases leakiness, and susceptibility to fungal rots. Calcium inhibits certain enzymes released by fungi during infection to break down the lamella that holds plant cells together, and so is particularly important for host resistance. B is particularly important in the synthesis of the defence compounds and so is important for host resistance.

Excessive nitrogen, on the other hand, can increase susceptibility to rots. This is partly due to its inhibitory effect on phytoalexin production and on silicon (Si) concentrations.

Accumulation of Si in the cell walls helps to form a protective physical barrier to fungal penetration. It is known that foliar applications of potassium silicate can reduce the severity of powdery mildew, which is an important disease of courgette (Menzies et al. 1992).

A study by Warncke (2007), Table 7, compared the response of different cucurbits to applications of micronutrients in situations where the initial soil level was low. It is notable from the results that the response to manganese addition was generally strong. In the UK, pumpkin, in particular, responds to Mn deficiency very quickly, therefore Mn supplementation is beneficial.

Table 8 shows the range of mineral contents for courgette, which were collated over several internet sites. The sites focused on the composition of courgettes in terms of its contribution to human nutrition. The authors did not link information on mineral contents to the postharvest keeping qualities of courgettes.

Further information on the effects of calcium nutrition in cucurbits can be found in the AHDB Horticulture project FV 457 report – *Calcium Nutrition in Cucurbits*.

Table 7. The response of cucurbits to application of micronutrients when the soil level is low

Crop	Boron (B)	Copper (Cu)	Manganese (Mn)	Zinc (Zn)
Cucumber	L	M	H	M
Muskmelon	M	M	H	M
Watermelon	M	L	M	M
Pumpkin	M	L	H	M
Squash	L	L	H	M

H = high, M = medium, L = low

Source: Warncke 2007 Indiana CCA Conference Proceedings Nutrient Management for Cucurbits: Melons, Pumpkin, Cucumber, and Squash (Darryl D. Warncke).

Table 8. The response of cucurbits to application of micronutrients when the soil level is low

	Mineral							
	Na	K	Ca	Fe	Mg	Mn	P	Zn
Content mg/100 g fresh weight	1–8	200–260	15–30	0.4–2.4	6–33	0.2–0.4	7–93	0.3–0.8

Postharvest storage strategies

Cooling

Courgettes will display shrivelling (dehydration) quickly if not cooled promptly after harvest. No published studies on the impact of cooling rates on courgette storage nor on the protocols for reducing field heat in courgettes were found by the authors of this publication at the point of writing.

Chlorine washing

Courgettes are easily bruised and so are not ideal for washing. However, in the US, chlorine washing of pumpkins is recommended in many states. In North Carolina, the recommendation is “When pumpkins are harvested a long time before sale, they should be washed or dipped in a 10% chlorine (bleach) solution (1 part chlorine bleach to 9 parts of water) and stored in a dry, cool place to reduce the chances of postharvest rots. Storage in the open sun causes excessive spoilage” – Jonathan R. Schulthe, Extension Horticultural Specialist Department of Horticultural Science, North Carolina Cooperative Extension Service, North Carolina State University.

Curing

The term ‘curing’ as used for different crops can be confusing; in some cases, such as potato tubers, it refers to maintaining the produce at warm temperatures and high humidity for several days to allow the natural process of wound-healing and periderm thickening. In that case, low humidity will inhibit the process. However, in other commodities, such as onion, ‘curing’ implies a drying-out process to provide a dry outer layer, and drying of stems.

In the case of pumpkin, most of the literature refers to the ventilation of the crop to dry, at the start of storage.

However, in some cases, there is also an indication that wound-healing should be promoted. For example, a quote from literature on winter squash in New York (Crop Profile for Squash in New York, USDA) suggests “Once harvested, winter squashes may be marketed immediately, or cured (held at moderate temperatures and high humidity to cure rinds and suberize any wounds)”. Likewise, in the US, the optimal conditions for storing pumpkin are quoted as 10–13°C and 50–70% humidity.

Curing for 10–20 days at 24–27°C is recommended before storage for pumpkins and winter squashes (Mark Gaskell University of California Cooperation Extension Pumpkin Production in California. Publication 7222, 1–4). Although high humidity is not mentioned, the higher temperature implies the promotion of biological healing.

The process of ventilating a large volume of pumpkins requires large amounts of energy, which is expensive. The industry would benefit from a set of maturity indicators that could be used to determine optimum drying protocols for each crop.

Heat treatment

Heat treatment was originally developed as a method of quarantine against insects, especially for the export of produce to countries that would not accept produce previously exposed to insecticides. However, in some cases, heat treatments have been found to have benefits for the quality of the produce itself – extending storage potential and reducing susceptibility to chilling injury (see section 4.3). A few examples of findings relating to cucurbits, including melons, are given here as examples. The results are mixed; in some cases, significant-quality benefits were seen, whereas in others the opposite was observed.

Mayberry and Hartz (1992) applied heat treatment to cantaloupe melons for 3 minutes with 60°C water, prior to storage at 3°C. Fruits had excellent appearance and firmness, and showed no stem-end decay up to 28 days of storage; untreated control fruits, however, were unmarketable. 'Galia' melons were free from decay up to 8 days at 20°C following immersion in 52°C water for 2 minutes; however, off-flavours were noted (Teitel et al. 1989). Dry heating the surface of the melons to 52°C did not reduce decay. Teitel et al. (1991) found that 'Galia' melons could be dipped for 1–2 minutes in 55°C water and immediately wrapped with PVC plastic film; acceptable quality was maintained for up to 9 days at 18°C storage. Heat injury symptoms ranged from small pits to general browning up to 50% of the fruit surface.

Hot water treatments did not reduce decay or extend the postharvest life of winter squash. 'Delica' was immersed for up to 12 minutes at 50°C; after 12 weeks of storage, there was no difference from untreated fruit (Arvayo-Ortiz et al.1994).

Courgettes were disinfested by a high humidity hot air treatment (HT) to a fruit core temperature of 45°C for 30 minutes and then stored at 7–8°C. Skin yellowing (indicated by percentage yellowing and machine colour measurements) generally increased with storage time and was exacerbated by HT. While courgette quality can be maintained for up to 11 days following HT, it appears that chilling injury prior to such treatment reduces the ability of the fruit to withstand this method of disinfestation (Jacobi et al. 1996).

Hot water treatment of squash (*Cucurbita maxima* Dutch 'Delica') was used to decrease fungal damage occurring during long transportation in Mexico. Hot water treatment decreased water loss in fruits but did not reduce fungal damage. The length of hot water treatment did not have an effect on the weight loss, decay, B-carotene and chlorophyll content (Arvayo-Ortiz et al. 1994).

Research (with muskmelons) suggests that pumpkins and winter squash may benefit from being dipped in 135–140°F (57–60°C) water for 3 minutes, and dried quickly before storage. Warm, wet fruits are subject to invasion by microorganisms, therefore drying and cooling to the storage temperature would have to be done immediately following this treatment. This hot water treatment surface sterilises the fruit.

No benefit has been found from chlorination of the hot water, but gently wiping the surface clean with 1 part household bleach in 10 parts of water may be helpful (Mansour, 2009).

Heat stress can trigger a response that makes tissues resistant to a range of other stress. For example, for many commodities, a pre-storage treatment involving exposure to high temperatures can impart some resistance to chilling injury. Kang et al. (2002) reported that greenhouse-grown cucumbers at average daytime temperatures of 32°C were more resistant to chilling injury and remained firmer during subsequent storage at 10°C than cucumbers grown at 27°C.

Non-destructive detection of injury and disorders pre-store

In many cases, internal mechanical injuries are not readily apparent during sorting and grading operations. Methods to detect these defects non-destructively in cucurbits have been studied, although primarily in cucumbers. However, the same techniques may be applicable to courgettes.

Cucumbers subjected to an impact were measured with refreshed delayed light emission, and differences in pericarp chloroplasts could be detected as soon as one hour after impact (Abbott et al. 1991). In a later study, Miller et al. (1995) successfully sorted fresh, whole cucumbers with damaged carpels from sound fruits using visible-infrared light transmission. Volatiles (ethanol, acetaldehyde) from low oxygen stress have been reported for cucumber (Kanellis et al. 1988); other studies also indicate that volatiles may serve as indicators of fruit quality or disease (Forney & Jordan 1998), but the commercial application of the latter method remains a challenge.

More recently, there has been great interest in developing non-destructive methods for assessing the quality of fresh produce. Although most of these have focused on high-value fruits, many of them could be used for cucurbits if economically advantageous. The technologies may be divided into those that consider produce shape, structure, and composition: machine vision, near-infrared spectroscopy, hyperspectral imaging, magnetic resonance and X-rays; and those that provide information on the metabolic status of the produce: volatile synthesis, respiratory characteristics, and chlorophyll fluorescence.

Coatings

Immature fruits, such as cucumber and summer squash, have underdeveloped cuticles and, consequently, readily lose moisture during handling. In the US, slicing cucumbers are typically coated with edible wax, while European greenhouse types are placed in shrink-wrap plastic film to control moisture loss. Permeability of wax and edible coatings to water, oxygen and carbon dioxide varies and must be matched with the respective fruit but coatings may have the potential to increase storage life in courgette, with thin wax (Hagenmaier & Shaw 1992; Baldwin et al. 1999). With the current concerns about plastic waste, the possibility of replacing cucumber sleeves with an edible coating is likely to be acceptable to consumers.

Figure 7. Cucumber in shrink-wrap plastic film

Modified and controlled atmosphere storage

Modification of the atmosphere ranges from maintaining high relative humidity within a package or pallet via plastic films, to changing the composition of the atmosphere surrounding the product. Using low oxygen and/or elevated carbon dioxide atmospheres slows metabolism and is, therefore, used to extend the storage life of many commodities. Maintaining high relative humidity (90–95%) is accomplished with the use of films or packing in vented clamshell containers. Care must be taken to avoid condensation on the product to minimise growth of decay organisms during handling and storage. For this reason, winter squashes are stored at lower relative humidities of 50–70%.

The findings relating to the range of cucurbits considered in this review are mixed. Elevated carbon dioxide (greater than or equal to 5%) has been reported to reduce chilling sensitivity in courgette (Suslow & Cantwell 2013). The effects of reduced oxygen are less clear. For example, courgettes exhibited less visible chilling injury symptoms when stored at 2.5°C and in low oxygen (4%), but after transfer to air at 10°C for 2 days, chilling injury symptoms developed. Severe off-flavours developed after storage at 2.5°C or 10°C; some were even more apparent after cooking (Mencarelli et al. 1983). On the other hand, Wang and Qi (1997) found that chilling injury of courgette (*Cucurbita pepo* L., cultivar 'Ambassador') was reduced by a low-oxygen atmosphere. The extent of surface pitting after exposure to 2.5°C was less under 1% oxygen than when kept in air.

Low-oxygen-stored squash also maintained higher levels of polyamines that are necessary to protect tissues against stress. Higher levels of spermidine and spermine were maintained during storage at 2.5°C or 12.5°C. Putrescine and spermidine in the skin tissue increased in response to exposure to chilling temperature. However, no significant increase of these polyamines was detected during storage at the non-chilling temperature. Boyhan et al. (2012) studied the effects of controlled atmosphere storage (3% O_2, 5% CO_2, 50°F (10°C), and 60% RH) on pumpkins, but did not see clear advantages.

Ethylene management

As mentioned previously, exposure to ethylene gas during storage or transport can accelerate senescent processes in non-climacteric cucurbits (fruit that does not ripen further after harvest). There is increasing interest in the fresh produce industry in the use of ethylene scrubbing technologies to remove ethylene from the atmosphere in stores. It is not known at this point what concentration of ethylene is present in courgette stores and, therefore, what impact ethylene removal would have.

A specific problem that was mentioned by UK courgette growers during the development of this review was that of delayed abscission of courgette flowers, leading to increased blossom end rots. Payan et al. (2006) reported that a high incidence of courgettes with attached flowers was caused by reduced ethylene production in the flower buds. They supported this hypothesis by demonstrating that the use of ethylene inhibitors increased the number of attached flowers, for several courgette cultivars. They also showed that the incidence of this characteristic was cultivar-dependent and correlated with low ethylene production phenotype. Two implications of their findings were, firstly, that the characteristic could be counteracted by selecting for cultivars with high ethylene production, and, secondly, the possibility that ethylene treatment in the field could be used to avoid the problem.

1-MCP

1-methylcyclopropene (1-MCP) is a chemical that blocks ethylene effects. In the UK, it is widely used to extend the storage of apples by slowing down the ripening processes. It is becoming commercialised for treating a wider range of fruits and vegetables to slow down the processes triggered by ethylene such as ripening and senescence. It is active in extremely low concentrations, <1 ppm (Blankenship & Dole 2003). However, for various reasons, 1-MCP treatment is not effective in all cases. With respect to cucurbits, 1-MCP slows ripening in netted melon. Senescence of watermelon and cucumber was accelerated with exposure to 40 ppb ethylene, whereas pretreatment with 1-MCP negated this effect (Sargent & Maynard 2012). It is possible that 1-MCP treatment could be used to extend storage life of courgette, but, to our knowledge, this has not yet been tested.

Ozone treatment during storage

Ozone (O_3) is a well-known strong oxidising agent used by the fresh produce industry as an antimicrobial agent for a number of years. In contrast to other sanitisers, it does not leave chemical residues on the surface of fresh produce (Khadre et al. 2001; Guzel-Seydim et al. 2004). It has been demonstrated in a number of studies that microbial contamination can be reduced by applying ozone in either gaseous (Aguayo et al. 2006; Tzortzakis et al. 2007; Selma et al. 2008; Horvitz and Cantalejo 2012) or aqueous form (Achen & Yousef 2001; Garcia et al. 2003; Akbas & Olmez 2007; Alexandre et al. 2011; Alexopoulos et al. 2013).

In recent years, there has been increasing interest in the use of ozone to improve fresh produce quality (appearance, texture and/or nutritional content). While single cellular organisms (fungi and bacteria) are more sensitive to ozone, the gas is reactive and can damage stored commodities.

The dosage of ozone applied should be optimised for each type of commodity.

A study was carried out to determine the effect of exposure to a low level of ozone (100 ppb) on visual and textural quality changes during the storage of courgettes (Glowacz et al. 2015). Ozone appeared to slow down water loss. Hence, a higher fresh weight (FW) loss was observed in air-stored (control) courgettes when compared with the ozone-exposed treatments (Figure 8).

An observation of economic importance was that whole fruit firmness of courgette is better maintained in samples exposed to ozone (Figure 9). A significant (P<0.05) difference was observed after 10 days of storage.

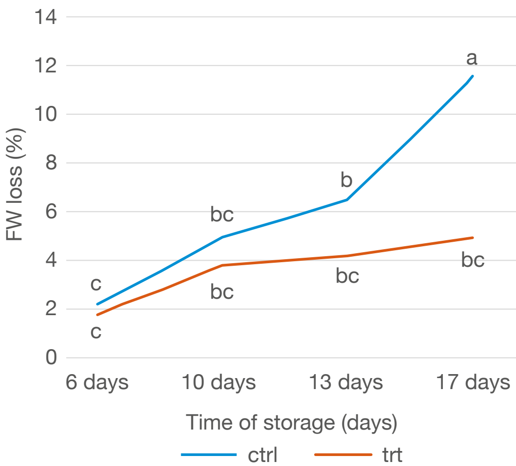

Figure 8. Effect of ozone treatment on fresh weight (FW) loss [%] during the storage of courgettes for 17 days at 8 °C. Data represent mean values from 12 replicates. Different letters indicate that values are significantly different (P<0.05)

(Reproduced from Glowacz et al., 2015)

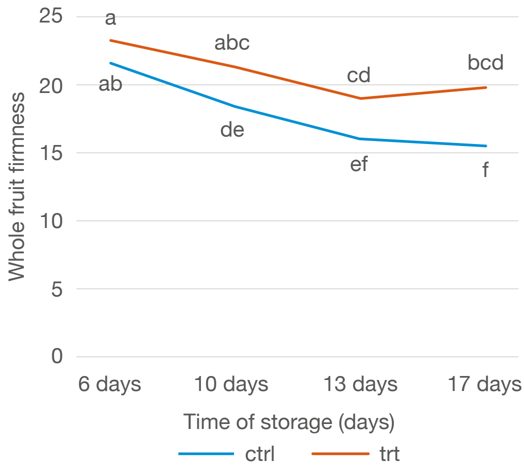

Figure 9. Effect of ozone treatment on whole fruit firmness [N] during the storage of courgettes for 17 days at 8 °C. Data represent mean values from 12 replicates. Different letters indicate that values are significantly different (P<0.05)

(Reproduced from Glowacz et al., 2015)

Decontamination using ultraviolet light

Ultraviolet light can be used as a decontamination technology. As with ozone, the treatment of surface has to be as gentle as possible to ensure the integrity and the freshness of fruits and vegetables. However, the use of UV light treatment has proved to be effective at reducing microbial loads of pathogens on a range of fresh fruits and vegetables.

Erkan et al. (2001) have looked at the use of a 10–20-minute treatment of sliced courgettes with UV-C (254 nm) and found it to be effective in reducing the effects of microbial contamination. Significant reduced microbial activity and deterioration was observed during subsequent storage at 5°C or 10°C.

Potential areas for further research

The following topics have been selected as potential areas of research that may benefit the UK cucurbit production industry.

Prevention of chilling injury in courgette using modified atmosphere packaging, or controlled atmosphere storage

Although chilling injury of courgettes was not identified directly as a priority problem during discussions with members of the industry, it limits the storage temperature, thereby reducing storage life. Further, the identification of pitting (a classic symptom of chilling injury) as a research priority by the UK Outdoor Cucurbits Growers' Group suggests that it does occur. Given the short storage times, modified atmosphere packaging using retail packs is probably the most practical way to apply this technology. Some research in this area has been carried out, with mixed results. However, a careful study to test potential options would be merited.

Storage of courgettes with low concentrations of gaseous ozone

Postharvest rots of courgette particularly gummosis caused by *Cladosporium cucumerinum*, have been mentioned as a major problem by industry representatives, especially following slow abscission of the flower. Low concentrations of ozone have been tried by some commercial companies to sanitise stores, to reduce rot pathogen growth. Additional quality improvements have also been noted for some commodities. Preliminary trials carried out by the Natural Resources Institute on the effects of low concentrations of ozone (100 ppb) on courgettes over 17 days storage have indicated reduced weight loss and better maintenance of texture.

The use of ethylene to speed up abscission of the flower for courgettes

A specific problem mentioned by the industry is the delayed abscission of courgette flowers, leading to increased blossom end rots. Ethylene controls flower senescence and the production of the abscission layer that promotes flower detachment. It is possible that the development of some form of ethylene treatment in the field could be used to speed up flower detachment and the healing of the abscission zone when this problem occurs.

Developing maturity indicators to predict the storage potential of pumpkins at harvest

The process of ventilating a large volume of pumpkin crop at the start of storage requires a large amount of energy and, therefore, expense. The industry would benefit from a set of maturity indicators that could be used to determine the storage potential and, therefore, the amount of drying needed for each batch. Additionally, it would be advantageous to understand whether there is value in including a period of 'curing' to allow healing of harvest wounds.

Ethylene management within stores

Ethylene promotes deterioration, and courgette is known to be moderately sensitive to ethylene effects. It is not known at this point what concentration of ethylene is present in courgette stores and, therefore, what impact ethylene removal would have. A short study to determine ethylene concentrations in stores and how this relates to sensitivity would be valuable.

Coating of immature cucurbits for retail

The literature states it is a reasonably common practice to reduce water loss through the coating of immature cucurbits, but the authors are unaware of this practice in the UK. As edible coatings are now available, it would be interesting to understand whether there are any UK scenarios where this might be an economically advantageous practice.

Ensure there is an accurate categorisation of varietal differences in storability

For the commodities included in this review, varietal differences in postharvest behaviour are often referred to in the literature. Very little information on UK varieties could be found. The industry might benefit from an accurate categorisation of the varietal characteristics, especially for courgette, to aid management decisions.

The impact of different mechanisms and rates of cooling on courgette storage quality

Courgettes will display shrivelling (dehydration) quickly if not cooled promptly after harvest. It may be useful to investigate the various mechanisms used to cool courgettes and any information on the impact on subsequent quality.

Appendix 1

The role of ethylene in the deterioration of fruit and vegetables

Ethylene gas (C_2H_4) is produced naturally by most plant tissues, especially ripening fruit. It is a plant hormone that controls many biological processes. Among plant hormones, ethylene is unusual because it is a gas. The implication of this is that if one plant or plant organ starts to produce ethylene, nearby plant tissues are also affected. For plants, many processes involving tissue death, such as leaf drop in deciduous trees, petal drop in flowers, over-ripening of fruit, are actively controlled as part of the natural life cycle. Many of these are controlled/stimulated by ethylene. For this reason, ethylene can speed up deterioration in fruits and many vegetables, particularly leafy greens.

As it controls so many processes associated with the quality of fruit and vegetables, ethylene is an extremely important chemical for the fresh produce handling industry. On the one hand, it is used to trigger ripening in fruits. Thus, bananas are transported green to the UK and are then stimulated to ripen by being fumigated with ethylene within warm ripening rooms. On the other hand, as ethylene will stimulate deterioration and senescence (an active process of cell death that leads to tissue deterioration), it is important to control concentrations to maintain quality. Thus, there is a growing recognition of the importance of controlling ethylene in fresh produce store-rooms, and, therefore, an increase in the use of ethylene scrubbers.

The concentrations at which ethylene can affect produce are low. There is evidence that many products are sensitive to concentrations well below 100 parts per billion (ppb). Ethylene is known to build up in packhouses to concentrations near 1,000 ppb (= 1 part per million (ppm)), which is above the threshold of sensitivity of most produce. A study conducted on a range of produce showed a 60% extension of postharvest life when stored in <5 ppb compared with 100 ppb ethylene[1].

[1] Wills, R.B.H., Ku, V.W., Shohet, D. and Kim, G.H. (1999) Importance of low ethylene levels to delay senescence of non-climacteric fruit and vegetables. Australian Journal Of Experimental Agriculture, 39 (2), 221–224

The biochemistry of how ethylene controls plant processes is complex and beyond the scope of this appendix. However, to relate the observation of ethylene levels to their likely effects on fresh produce, it is useful to understand some of the background principles.

Processes controlled by ethylene can be classified into two types:

System 1. Ethylene 'stimulates' the process

If ethylene concentrations are increased, the process goes faster, and if ethylene concentrations are reduced or ethylene is removed completely, the process slows/stops. This system applies to ethylene stimulation of the deterioration/senescence of vegetables, over-ripening/senescence of fruit, discolouration of cucumber and browning of broccoli.

System 2. Ethylene acts as a switch that cannot be stopped

Thus, ethylene triggers a biological process. If ethylene levels are reduced, or ethylene is removed completely, the process continues, albeit at a slower pace. This is the case for the initiation of ripening of certain fruits, known as 'climacteric fruit'. These include bananas, apples, tomatoes, kiwi fruit, pears and avocados, but not grapes, oranges and lemons.

Figures 11 and 12 demonstrate some of the effects of exposure to ethylene.

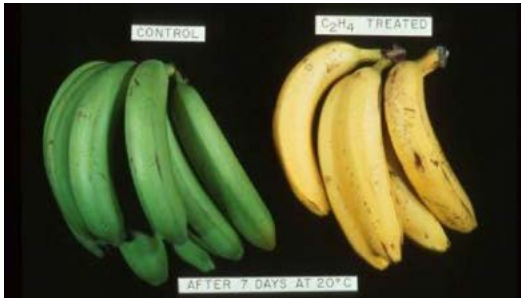

Figure 10. Ethylene treatment triggers the ripening of bananas, which are climacteric fruit and, therefore, need only temporary exposure (System 2)

Figure 11. Exposure to ethylene can induce colour loss of cucumbers. This is a natural 'ripening' process, but detrimental to the quality

Figure 12. Exposure to ethylene can induce browning in green vegetables, as shown in this example of broccoli stored with and without ethylene in the storage atmosphere

Appendix 2

Nutritional composition of cucurbits (amounts per 100 g fresh product)

Cucurbit	Water (%)	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)	Fiber (g)	Ca (mg)	P (mg)	Fe (mg)
Pumpkin	92	26	1.0	0.1	6.5	1.1	21	44	0.8
Pumpkin flowers	95	15	1.0	0.1	3.3	–	39	49	0.7
Pumpkin leaves	93	19	3.2	0.4	2.3	–	39	104	2.2
Pumpkin seeds*	7	541	24.5	45.9	17.8	3.9	43	807	15
Squash, acorn	88	40	0.8	0.1	10.4	1.5	33	36	0.7
Squash, butternut	86	45	1.0	0.1	11.7	1.4	48	33	0.7
Squash, hubbard	88	40	2.0	0.5	8.7	1.4	14	21	0.4
Squash, scallop	94	18	1.2	0.2	3.8	0.6	19	36	0.4
Squash, summer	94	20	1.2	0.2	4.4	0.6	20	35	0.5
Squash, winter	89	37	1.5	0.2	8.8	1.4	31	32	0.6
Courgette	96	14	1.2	0.1	2.9	0.5	15	32	0.4

Cucurbit	Na (mg)	K (mg)	Vitamin A (IU)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Ascorbic Acid (mg)	Vitamin B_6 (mg)
Pumpkin	1	340	1600	0.05	0.11	0.60	9.0	–
Pumpkin flowers	5	173	1947	0.04	0.08	0.69	–	–
Pumpkin leaves	11	436	1942	0.09	0.13	0.92	11.0	0.21
Pumpkin seeds*	18	535	380	0.21	0.32	1.75	–	0.22
Squash, acorn	3	347	340	0.14	0.01	0.70	–	0.15
Squash, butternut	4	352	7800	0.10	0.02	1.20	21.0	0.15
Squash, hubbard	7	320	5400	0.07	0.04	0.50	11.0	0.15
Squash, scallop	1	182	110	0.07	0.03	0.60	18.0	0.11
Squash, summer	2	195	196	0.06	0.04	0.55	14.8	0.11
Squash, winter	4	350	4060	0.10	0.03	0.80	12.3	0.08
Courgette	3	248	340	0.07	0.03	0.40	9.0	0.09

*Dried. Source: U.S. Dept. Agric. 2002. **bit.ly/30sXAPc**

References

Abbott, J. A., Miller, A. R, and T. A. Campbell, T. A. (1991). Detection of mechanical injury and physiological breakdown of cucumbers using delayed light emission. J. Amer. Soc. Hort. Sci. 116(1): 52–57.

Achen, M. and Yousef, A. E. (2001). Efficacy of ozone against *Escherichia coli* O157: H7 on apples. *Journal of Food Science*, 66 (9): 1380–1384.

Aguayo, E., Escalona, V. H. and Artes, F. (2006). Effect of cyclic exposure to ozone gas on physicochemical, sensorial and microbial quality of whole and sliced tomatoes. *Postharvest Biology and Technology*, 39: 169–177.

Alexandre, E. M. C., Santos-Pedro, D. M., Brandao, T. R. S. and Silva, C. L. M. (2011). Influence of aqueous ozone, blanching and combined treatments on microbial load of red bell peppers, strawberries, and watercress. *Journal of Food Engineering*, 105: 277–282.

Alexopoulos, A., Plessas, S., Ceciu, S., Lazar, V., Mantzourani, I., Voidarou, C., Stavropoulou, E. and Bezirtzoglou, E. (2013). Evaluation of ozone efficacy on the reduction of microbial population of fresh-cut lettuce (*Lactuca sativa*) and green bell pepper (*Capsicum annuum*). *Food Control*, 30: 491–496.

Akbas, M. Y. and Olmez, H. (2007). Effectiveness of organic acid, ozonated water and chlorine dippings on microbial reduction and storage quality of fresh-cut iceberg lettuce. *Journal of the Science of Food and Agriculture*, 87: 2609–2616.

Arvayo-Ortiz, R.M., Garza-Ortega, S. and Yahia, E. M. (1994). Postharvest response of winter squash to hot water treatment, temperature, and length of storage. HortTechnology 253–255 (Mexico).

Baldwin, E. A., Burns, J. K, Kazokas, W. Brecht, J. K., Hagenmaier, R. D. , Bender, R. J. and Pesis, E. (1999). Effect of two edible coatings with different permeability characteristics on mango (*Mangifera indica* L.) ripening during storage. Postharv. Bio. Tech. 17: 215–226.

Blankenship, S. and Dole, J. (2003). 1-Methylcyclopropene: A Review. Postharv. Biol. Technol. 28: 1–25.

Boyhan, G. E., MacLean, D., Bateman, A. G. and Tate, S. (2012). Preliminary Evaluation of Modified-Atmosphere Storage for Pumpkins. International journal of vegetable science 18: 87–92.

Cantwell, M and Suslow, T.V. (2013). Pumpkin and winter squash: Recommendations for maintaining postharvest quality. Produce Fact Sheets, UC Davis Postharvest Technology **postharvest.ucdavis.edu/pfvegetable/Pumpkin/** (accessed July 2013).

Carvajal, F., Martinez, C., Jamilena, M. and Garrido D. (2011) Differential response of zucchini varieties to low storage temperature. Scientia Horticulturae 130, 90–96. (Spain).

Defra Statistics, Horticultural statistics 2017.

Erkan, M., Wang, C. Y., Krizek, D. T. (2001). UV-C irradiation reduces microbial populations and deterioration in *Cucurbita pepo* fruit tissue. Environ. Exp. Bot. 45: 1–9.

Forney, C. F., and Jordan, M. A. (1998). Induction of volatile compounds in broccoli by postharvest hot-water dips. J. Agr. Food Chem. 46(12): 5295–5301.

Frost, D. J. and Kretchman D. W. (1989). Calcium deficiency reduces cucumber fruit and seed quality. J. Amer. Soc. Hort. Sci. 114(4): 552–556.

Garcia, A., Mount, J. R., and Davidson, P. M. (2003). Ozone and chlorine treatment of minimally processed lettuce. *Journal of Food Science*, 68 (9): 2747–2751.

Glowacz, M., Colgan, R. and Rees, D. (2015). Influence of continuous exposure to gaseous ozone on the quality of red bell peppers, cucumbers, and zucchini. Postharvest Biology and Technology, 99: 1–8.

Guzel-Seydim, Z. B., Greene, A. K., and Seydim, A. C. (2004). Use of ozone in the food industry. *Lebensmittel-Wissenschaft Und-Technologie-Food Science and Technology*, 37: 453–460.

Hagenmaier, R. D. and Shaw, P. E. (1992). Gas permeability of fruit coating waxes. J. Amer. Soc. Hort. Sci. 117: 105–109.

Horvitz, S. and Cantalejo, M. J. (2012). Effects of ozone and chlorine postharvest treatments on quality of fresh-cut red bell peppers. *International Journal of Food Science and Technology*, 47: 1935–1943.

Hyodo, H., Hashimoto, C., Morozumi, S., Ukai, M. and Yamada, C. (1993). Induction of wound ethylene production and lignin formation in wounded mesocarp tissue of Cucurbita maxima. Acta Hort. 343: 264–269.

Jacobi, K. K., Wong, L. S. and Giles, J. E. (1996). Postharvest quality of zucchini (Cucurbita pepo L.) following high humidity hot air disinfestation treatments and cool storage Postharvest Biology and Technology, 7: 309–316.

Kanellis, A. K., Morris L. L. and Saltveit, Jr. M.E. (1988). Responses of parthenocarpic cucumbers to low-oxygen storage. J. Amer. Soc. Hort. Sci. 113: 734–737.

Kang, H. M., Park, K. W. and Saltveit, M. E. (2002). Elevated growing temperatures during the day improve the postharvest chilling tolerance of greenhouse-grown cucumber (*Cucumis sativus*) fruit. Postharvest Biology and Technology, 24: 49–57.

Kays, S. J. (1991). Postharvest Physiology of Perishable Plant Products. Van Nostrand Reinhold, New York. p 532.

Khadre, M. A., Yousef, A. E. and Kim, J.G. (2001). Microbiological aspects of ozone applications in food: a review. *Journal of Food Science*, 66 (9): 1242–1252.

Lester, G. E. and. Grusak. M. A, (2001). Postharvest application of chelated and nonchelated calcium dip treatments to commercially grown Honey Dew melons: Effects on peel attributes, tissue calcium concentration, quality, and consumer preference following storage. HortTechnology, 11(4): 561–566.

Lester, G. E., Baizabal-Aguirre V. M., Gonzalez de la Vara L. E. and Michalke W. (1998). Calcium-Stimulated protein kinase activity of the hypodermal-mesocarp plasma membrane from preharvest-mature and Postharvest Muskmelon. J. Agric. Food Chem. 46: 1242–1246.

Locascio, S. J., Wiltbank, W.J., Gull, D. D., and Maynard, D. N. 1984. Fruit and vegetable quality as affected by nitrogen nutrition. ASA-CSSA-SSSA. pp 617–626.

Mansour N.S. (2009). Extension vegetable crops specialist, Oregon State University. **ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/12889/ec1632**

Mayberry, K. S., and Hartz. T. K. (1992). Extension of muskmelon storage life through the use of hot water treatment and polyethylene wraps. HortScience. 27(4): 324–326.

Maynard, D. M., Elmstrom, G. W., Talcott, S. T., and Bruce Carle, R. (2002). 'El Dorado' and 'La Estrella': Compact plant tropical pumpkin hybrids. HortScience 37(5): 831–833.

Mencarelli, F., Lipton, W. J. and Peterson S. J. (1983). Responses of 'zucchini' squash to storage in low-O2 atmospheres at chilling and nonchilling temperatures. J. Amer. Soc. Hort. Sci. 108(6): 884–890.

Menzies, J.G., Bowen, P., Ehret, D.L., Glass, A.D.M. (1992). Foliar applications of potassium silicate reduce severity of powdery mildew on cucumber, muskmelon, and zucchini squash. J. Amer. Soc. Hort. Sci. 117: 902–905.

Miller, A. R., Kelley T. J. and White, B. D. (1995). Non-destructive evaluation of pickling cucumbers using visible-infrared light transmission. J. Amer. Soc. Hort. Sci. 120(6): 1063–1068.

Payán, M. C., Peñaranda, A., Rosales, R., Garrido, D. Gómez, P. and Jamilena, M. (2006). Ethylene mediates the induction of fruits with attached flower in zucchini squash. Proceedings of Cucurbitaceae.

Sargent, S. A., and Maynard, D. N. (2012) Cucurbits. Chapter 14 in Rees, D., Farrell, G. and Orchard, J. E. (eds), (2012): Crop Post-harvest: Science and Technology. Volume 3 Perishables.

Selma, M. V., Ibanez, A. M., Cantwell, M. and Suslow, T. (2008). Reduction by gaseous ozone of Salmonella and microbial flora associated with fresh-cut cantaloupe. *Food Microbiology*, 25: 558– 565.

Suslow, T. V. and Cantwell, M. (2013). Squash (Soft rind) Recommendations for maintaining postharvest quality. Produce Fact Sheets, UC Davis Postharvest Technology **postharvest.ucdavis.edu/pfvegetable/Squash/** (accessed July 2013)

Teitel, D. C., Aharoni, Y. and Barkai-Golan R. 1989. The use of heat treatments to extend the shelf-life of 'Galia' melons. J. Hort. Sci. 64(3): 367–372.

Teitel, D. C., Barkai-Golan, R., Aharoni, Y., Copel Z. and Davidson, H. (1991). Toward a practical, postharvest heat treatment for 'Galia' melons. *Scientia Horticulturae*, 45: 339–344.

Tzortzakis, N., Singleton, I. and Barnes, J. (2007). Deployment of low-level ozone-enrichment for the preservation of chilled fresh produce. *Postharvest Biology and Technology*, 43: 261–270.

Wang, C.Y. and Qi, L. (1997). Modified atmosphere packaging alleviates chilling injury in cucumbers. Postharvest Biol. Technol. 10: 195–200.

Warncke, D.D. (2007). Indiana CCA Conference Proceedings Nutrient Management for Cucurbits: Melons, Pumpkin, Cucumber, and Squash.

Yeager, A.F. et al. (1945). The storage of Hubbard squash. N.H. Agr. Expt. Sta. Bul. 356: 15.

Produced for you by:
AHDB Horticulture
Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

T 024 7669 2051
E comms@ahdb.org.uk
W ahdb.org.uk
@AHDB_Hort

30018 1222