**Post-harvest application of SmartFresh Quality System**

The SmartFresh™ Quality System is commonly applied to apples in the UK and throughout the world to maintain harvest attributes. It is an important supplementary measure to good storage practice and is particularly effective in maintaining the quality of fruit in-store and during subsequent marketing and distribution.

Extensive research has been carried out at East Malling Research (EMR) since 2000 under the sponsorship of Rhône and Haas. Most of the research at EMR has been done on Bramley, Cox and Gala. SmartFresh™ was approved for use on UK apples in September 2003. Since that time there has been considerable commercial experience with the product with over 1,100 stores being treated between 2003 and 2006 (Tully, 2003; 2004; 2006; 2006; 2007).

The active ingredient of SmartFresh™ is 1-methylcyclopropene (1-MCP), a potent inhibitor of ethylene action in plants. As it is very similar in its chemical structure to ethylene, it binds preferentially with ethylene receptors in the cells of the fruit at the beginning of fruit storage. Consequently, for a period after SmartFresh™ application, apples are insensitive to ethylene and consequently ripening events are retarded.

SmartFresh™ is formulated as a powder that releases 1-MCP when mixed with water in the storage room. The process takes about 24 hours and does not leave any detectible residue on the apples or in the environment.

The application protocol decided universally for apples, based on work done in the UK and elsewhere, is 625 parts per billion of 1-MCP (calculated for empty store volume) applied for 24 hours with minimal delay between harvest and application.

SmartFresh™ is part of a quality control system and growers need to use the application service provided by Landseer Ltd, the nominated representatives of Agrofresh.

Once the suitability of the rooms has been determined, commercial applicators are prepared with an amount of SmartFresh™ that is appropriate for the volume of the store to be treated. Water is added and circulated through the SmartFresh™ via an integral battery-driven pump. The applicator is then inserted into the sealed store where it remains for approximately 24 hours.

After treatment the store is operated normally.

Results of SmartFresh™ research done at EMR are summarised in reports of EMR Members’ Days on Top Fruit Storage (Johnson and Pearson, 2002; 2003) and elsewhere (Johnson, 2008). The benefits of SmartFresh™ for the main UK cultivars as determined from research done at EMR and from commercial experience are summarised below.

**Cox’s Orange Pippin (and clones) – benefits**

- SmartFresh™ application provides a significant (>2-fold) extension to the storage life of fruit held in refrigerated air storage.
- A combination of a lower storage temperature (1.5°C) and SmartFresh™ application was particularly beneficial to the quality of air-stored fruit.
- SmartFresh™ application consistently improved retention of firmness and reduced weight loss in store.
- Occasionally SmartFresh™ application resulted in reduced yellowing, higher soluble solids and acidity levels and less bitter pit.
- Greatest effects of SmartFresh™ application were achieved on fruit picked at the correct stage of maturity for medium to long-term storage.

**Stem end russet browning**

In some commercial consignments of Cox treated in the UK and also in New Zealand the russetted areas of the fruit have darkened in response to SmartFresh™ application. This known as stem end russet browning.

- The precise cause of the disorder is unknown although it has been hypothesised that 1-MCP causes a stress response in the skin cells which leak cell contents that are rapidly oxidised to brown coloured compounds (McCormick and Streif, 2008).
- Development of browning symptoms is inhibited by low temperatures and low oxygen conditions so fluctuations in temperature or atmosphere after treatment should be avoided.
- Commercial experience also suggests that early picked fruit are particularly at risk from stemend russet browning.
- Tables of storage conditions for Cox contain information to remind growers of practices that minimise this disorder.
- It is advised by the suppliers (Landseer Ltd.) that SmartFresh™ application should be restricted to fruit where starch coverage is 70% or less.
- This is to minimise the effects of stemend russet browning and encourage fruit above 75% starch and a pressure greater than 8.6 kg to be stored for March marketing without the use of SmartFresh™.

**Core flush**

Perhaps the most significant adverse effects of SmartFresh™ is the increased susceptibility of stored fruits to core flush and flesh breakdown which has important limitations on the storage life of Cox stored in CA conditions.

- In air storage, core flush was evident in fruit treated with SmartFresh™ after 90 days but not after 60 days.
- It is difficult to set a precise termination date for air-stored Cox apples treated with SmartFresh™.
- It is currently advised that marketing should be concluded in December although regular monitoring of fruit condition will help determine more precisely the termination dates for particular consignments.
- The life of Cox apples treated with SmartFresh™ and stored in CA conditions is limited by the development of core flush and flesh breakdown.
- The termination month for treated fruit is set at January but it may be possible to extend storage of some consignments, particularly in years when climatic conditions have conferred a low potential for core flush and low temperature breakdown.
- It is possible to make a general assessment of risk based on seasonal weather (Johnson and Ridout, 1998) but careful monitoring of the condition of the stored fruit is required to determine when to conclude storage.

**The storage of SmartFresh™-treated Cox beyond January**

Growers wishing to extend the storage of SmartFresh™-treated Cox beyond January are advised to store in CA conditions of 1.2% O₂ and <1% CO₂ and to ensure that fruit temperature is above 3.5°C in all parts of the store.
Bramley's Seedling – benefits
The effect of SmartFresh™ in reducing scald development is the most commercially significant effect since it makes possible the storage of Bramley without the post-harvest application of DPA. Bramley apples treated with SmartFresh™ and stored in conventional ventilated CA conditions (9% CO₂ + 12% O₂) should remain free of scald until March and those stored in scrubbed low oxygen (5% CO₂ + 1% O₂) should remain free of scald until July.

- SmartFresh™ application consistently improved retention of firmness and reduced weight loss in store.
- SmartFresh™ application provided greener, more acid fruit that were less susceptible to superficial scald and bitter pit.
- Occasional beneficial effects of SmartFresh™ application included higher soluble solids in the fruit and reduced incidence of senescent breakdown and core flush.
- Greatest effects of SmartFresh™ application were achieved on fruit picked at the correct stage of maturity for long-term storage.
- Growers should continue to select for long-term storage those orchards that comply with recommended standards for fruit mineral analysis.
- Regular and rigorous monitoring of the condition of fruit from store is essential and should include a shelf-life test to provide an indication of scald potential.

There is significant orchard variability in the quality of Bramley apples treated with SmartFresh™ (Johnson, 2008) which demonstrates the need to maximise storage potential through attention to pre-harvest factors (see Sections 1, 2 and 3). To minimise scald risk in Bramley there should be no more than 3 days between picking and application and fruit should be stored in a scrubbed low oxygen regime.

Bramley's Seedling – constraints / limitations
Bramley apples not treated with DPA after harvest are susceptible to external CO₂ injury when stored in recommended CA conditions.

- It is necessary to delay the establishment of CA conditions where DPA is not used in order to alleviate the problem (Johnson et al., 1998).
- Application of SmartFresh™ without the use of DPA caused CO₂ injury in Bramley apples stored in 5% CO₂ + 1% O₂ (5/1) despite a 10-day delay in establishing CA conditions.
- For SmartFresh™-treated fruit, it is recommended that the delay in establishing CA conditions is extended to 21 days.
- During this period the oxygen concentration in 5/1 stores can be allowed to decline to 10% but the CO₂ concentration should be scrubbed to <1%.

Post-harvest application of DPA should negate any risk of CO₂ injury in SmartFresh™-treated fruit and eliminates the need to delay establishment of CA conditions.

- Delay in establishing CA conditions would normally be considered to conflict with best practice but it is necessary to ameliorate the risk of CO₂ injury in Bramley apples not treated with DPA.
- The consequences of any delay in terms of reduced storage potential / quality are minimal in SmartFresh™-treated fruit as the ethylene production and ripening processes are slowed immediately after application.

Gala (and clones) - benefits

- SmartFresh™ application consistently improved retention of firmness of air-stored fruit and virtually eliminated softening in CA-stored fruit.
- SmartFresh™ application reduced weight loss in air-stored fruit.
- SmartFresh™ suppresses the development of skin greasiness.

Gala (and clones) - constraints / limitations

- No adverse effects of SmartFresh™ application on CA-stored (<1% CO₂ + 1.2% O₂) fruit.
- SmartFresh™ application aggravated core flush and flesh breakdown in fruits stored in air at 0-0.5°C for 180 days. The storage of SmartFresh™-treated fruit in refrigerated air should be terminated in January.

Egremont Russet - benefits

- SmartFresh™ application improved the quality of fruit stored in air and CA conditions.
- Fruit treated with SmartFresh™ prior to air storage for 90 days remained firm and free of scald and other disorders. However, extending storage in air to 180 days proved too long for SmartFresh™-treated fruit with fruits being affected by rotting, scald and internal disorders.
- The storage of SmartFresh™-treated fruit in refrigerated air should be terminated in December.
- SmartFresh™ application improved the firmness and reduced the development of breakdown and core flush in fruits stored in CA (5% CO₂ + 3% O₂) for 180 days. Termination dates for CA-stored fruit are similar for fruits treated or not treated with SmartFresh™.
Since Egremont apples produce very high levels of ethylene the application of SmartFresh™ should be carried out as soon as possible after harvest and preferably within 3 days.

Where SmartFresh™ has been applied to commercial stores of Egremont Russet improved control of bitter pit was evident in fruit picked at the mid-point of the harvesting 'window' and stored under appropriate CA conditions.

Egremont Russet - constraints / limitations

- There are concerns about the flavour quality of early-picked SmartFresh™-treated fruit removed from CA storage before Christmas.
- Consequently SmartFresh™ should not be used on early-picked fruit for pre-Christmas marketing.

Other dessert cultivars of apple

Only limited research has been carried out at EMR on other dessert cultivars although commercial experience of the effects of SmartFresh™ application is increasing. Lack of response in some of these preliminary trials may be due to harvesting fruit too late or removing fruit from store too early when untreated fruit may not have softened sufficiently to establish any potential firmness differences. For the latest information on the use of SmartFresh™ on UK-grown apples contact the supplier, Landseer Ltd.

Jonagold, Idared and Fiesta

- CA-stored fruit responded well to SmartFresh™ application in terms of firmness retention.

Spartan and Meridian

- No significant response to SmartFresh™ application in fruit stored in CA for 90 days at EMR.
- However, in commercial SmartFresh™ applications carried out over the past four years a firmness benefit was found in both varieties.

Braeburn

- Although Braeburn responded well in terms of firmness retention, SmartFresh™ application induced core flush in 75% of fruits.
- Since development of core flush currently limits the storage life of CA-stored Braeburn. It is clear that SmartFresh™ application cannot be recommended for this cultivar.

Empire

No research has been carried out in the UK but it is clear from work done in the USA and Canada that SmartFresh™ application exacerbates the risk of external CO₂ injury.

- It appears that SmartFresh™ application extends the ‘adaptation’ period between harvest and establishing CA conditions (Razafimbelo et al., 2006) that is necessary to eliminate the risk of CO₂ injury.
- In response to the heightened risk of CO₂ injury due to SmartFresh™ application, it is recommended that the CO₂ concentration for CA-stored Empire apples is maintained below 0.5%.
- Successful commercial applications of SmartFresh™ have been made to Empire in the UK.

Other traditional dessert cultivars

The following cultivars were reported as showing a firmness increase following SmartFresh™ application when stored in air until Christmas (Tully, 2003):


Section 1. Optimising the pre-harvest management of orchards to maximise the storage and eating quality of fruits

Orchard management practice should always be geared towards maximum yields of class 1 fruit. The influences of such practices on storage quality need to be considered in order that appropriate marketing strategies can be put into place.

Where such practices adversely affect storage or eating quality, remedial measures need to be taken where these are available. The influence of pre-harvest factors on storage quality operate primarily through effects on yield, fruit size and vegetative growth.

Cropping level, fruit size and thinning

Large fruit from lightly cropping trees do not generally store well due to mineral imbalance in the fruit and to a low calcium concentration in particular.

Over-cropping trees produce small fruit that lack red colour and have insufficient dry matter for adequate texture, although the fruit is unlikely to develop physiological disorders associated with low calcium.

Vigorous growth competes with the developing fruit for available nutrients and water and can often exacerbate problems due to low calcium.

Judgement of the correct level of cropping to achieve sufficient yield, fruit size and visual quality without unduly compromising storage potential is paramount in achieving profitable production and commercial success.

Adequate thinning will help to ensure that harvest isn’t delayed beyond the optimum period for storage in an attempt to improve size and red colour.

Hand thinning Cox trees to one fruit per cluster at 35-40 days after full bloom has improved the texture and eating quality of CA-stored fruit.

Chemical thinning (see Part 1 of the Guide) at the appropriate stage followed by hand thinning as necessary is the best practice to achieve the desired level of crop.

Thinning sprays may indirectly increase susceptibility of apples to calcium deficiency disorders such as bitter pit and senescent breakdown by increasing fruit size and the leaf to fruit ratio.
The priority should be the achievement of the correct level of crop for profitable production but awareness of the effects of thinning on the mineral status of the fruit is essential for planning storage and marketing (see Section 3).

The lighter the crop the greater the requirement for supplementing calcium nutrition of the fruit by the use of calcium sprays (see Section 2), post-harvest calcium treatments (see Section 7) and of pre-harvest mineral analysis to predict storage potential (see Section 3).

**Rootstocks, pruning and shoot growth**

Avoid hard pruning in the winter and use an appropriate chemical growth regulator as a means of controlling shoot growth in the spring and summer months.

Late summer pruning reduces susceptibility of stored fruit to bitter pit and other calcium-deficiency disorders and improves red colour and the efficacy of calcium spraying in the orchard. However, this form of pruning should be limited to the **vigorous upright one-year-old shoots and not done too early** as re-growth may occur.

**Effects of orchard sprays**

Effects of the growth regulator "Cultar" (paclobutrazol) on the storage quality of Bramley apples have generally been positive but is known to induce diffuse browning disorder in Cox apples on some farms, particularly when used in conjunction with triazole fungicides such as myclobutanil or penconazole (see Section 13). Prohexadione ('Regalis') may be the preferred growth regulator for use in Cox orchards.

Growth regulators applied to improve skin finish ('Regules') do not appear to cause adverse effects on storage quality.

*Currently no growth regulators are available in the UK for use in the orchard to specifically improve storage quality of apples. 'RetainR' is a product approved and used in some parts of the world that contains an ethylene inhibitor (aminoethoxyvinylglycine or AVG).

"RetainR" is applied as an orchard spray to retard fruit maturity, extend the picking period for storage and delay the rate of ripening and senescence of fruit in store. Unfortunately plans to register this product for use in the UK have been abandoned by the manufacturers despite results on Cox, Gala and Bramley being particularly encouraging.

**Soil management and mineral nutrition**

Herbicide-based soil management may reduce phosphorus uptake into leaves and fruits and increase susceptibility of fruit to low temperature breakdown during storage. Apply phosphorus sprays (see Section 2) in Cox and Bramley orchards where phosphorus levels in the fruit are consistently low.

Ensure sufficient weed-free areas in Bramley orchards to reduce the competitive effects of grass on nitrogen uptake. Intense competition will reduce yield and fruit size and will promote red colour and reduce the intensity of greenness in the background colour.

Reducions in fruit phosphorus and calcium due to increased area of bare soil and nitrogen application should be countered by the use of orchard sprays containing phosphorus and calcium respectively.

Safeguard storage potential by routine application of calcium sprays and correct harvest date. Fruit on lightly cropping trees tend to be ready to harvest earlier than those carrying heavier crops. However, fruit from lightly cropping trees are likely to contain more starch and this can give a confusing picture of maturity based on the starch-iodine test. Results obtained with the starch-iodine test on young trees need to be interpreted carefully (see Section 4).

**Disorders of the flesh**

**B. Disorders of the flesh of the fruit**

**Occurring naturally during storage:**

**Senescent breakdown**

- This disorder is usually associated with over-maturity or over-storage and is accentuated by mineral imbalance in the fruit at harvest and particularly with inadequate calcium.
- Compliance with suggested mineral standards, harvesting at the correct stage of maturity, maintaining the correct storage conditions for the periods advised and prompt marketing of fruit after storage should avoid the problem.
- It is particularly difficult to distinguish different forms of breakdown on the basis of visual symptoms. The appearance varies between cultivars, and storage conditions have a major influence on expression of symptoms.
- Typically in air-stored Cox and Bramley apples (and sometimes in CA-stored fruit) senescent breakdown appears on the outside as a dull darkening of the skin that progresses inwards.
- However, in CA-stored fruit there may be a gradual discoloration of the flesh that can be confused with low temperature breakdown.
- In Gala apples (see figure) senescent breakdown generally affects the layers of tissue immediately below the skin and spreads around the fruit before progressing inwards.

**Low temperature breakdown**

- As with senescent breakdown the symptoms of low temperature breakdown (LTB) vary according to storage conditions and it is often difficult to be certain about the type of breakdown where the apple flesh is affected by a general browning.
- In air-stored Cox and Bramley apples areas of the cortical tissue affected by LTB appear similar to senescent breakdown.
- However, in LTB-affected apples there is normally a zone of healthy tissue immediately below the skin and the cut surface of affected tissue is usually moist when compared with senescent breakdown.
- LTB normally develops before fruits become overripe.
- Fruit kept in CA are more susceptible to LTB than those kept in air storage. Consequently higher storage temperatures and usually recommended for CA than for air storage (see Section 9).
Low temperature breakdown (air stored Cox)

- LTB symptoms in CA-stored fruit are different to those in air-stored fruit and take the form of a general browning of the cortical tissue and often there is a wedge-shaped pattern in the apple cortex. This is apparent particularly in Bramley but less so in Cox.
- LTB is a product of two factors, namely temperature and time of exposure.
- Short periods of exposure to low temperatures will not cause LTB.
- The disorder can occur at recommended storage temperatures.
- Cool growing seasons and late picking increase the susceptibility of Cox and Bramley apples to LTB. Prediction of LTB risk is possible based on climatic conditions during the growing season and mineral composition of the fruit at harvest.
- The disorder is progressive in store and may progress significantly in apples removed to ambient conditions.
- Immediate marketing is recommended when LTB is present in samples removed during store monitoring.

Water core breakdown

- As the name implies, water core breakdown is a flesh breakdown that develops in fruit affected by water core at harvest.
- The disorder is not common in apple cultivars grown in the UK since water core is not usually problematic (see water core below).

Diffuse browning disorder

- Referred to colloquially as ‘boggy bank disorder’ after the first reported occurrence in a Cox orchard of that name.
- Prior to 2000 there were few cases of diffuse browning disorder (DBD) causing significant problems in commercial fruit. However, the disorder has caused severe problems in some consignments of Cox apples since 2000.
- The disorder first appears as a localised browning of the flesh predominantly towards the calyx end of the fruit.
- The disorder progresses around the fruit and may progress to the inner cortex.
- Often there is a healthy band of tissue beneath the skin of the fruit so it is difficult to detect affected fruit from an external examination.
- Research done at EMR established a link between the application of orchard sprays containing triazole chemicals and the development of DBD in CA-stored fruit (Johnson, 2007; 2008a).
- Triazoles are compounds with a composition of $\text{C}_2\text{H}_3\text{N}_3$ having a 5-membered ring of 2 carbon atoms and 3 nitrogen atoms and include commonly applied fungicides such as myclobutanil (‘Aristocrat’ and ‘Symthane’) and penconazole (‘Topaz’ and ‘Topenco’) and the growth regulator paclobutrazol (‘Cultar’).
- In grower trials fungicide application was more conducive to DBD development than application of paclobutrazol but in combination induced the highest level of DBD.
- In these studies some orchards did not produce susceptible fruit despite application of triazole chemical sprays.
- Clearly other unknown factors determine whether the chemical stress exerted by the use of triazoles results in the development of clinical symptoms in stored fruit.
- In HDC-funded research carried out by FAST Ltd (HDC project TF 166f) ‘Symthane’ sprays induced slightly more DBD than ‘Cultar’ but by far the greatest induction of DBD occurred following application of ‘Topenco’.
- DBD in CA-stored fruit increased with increased number of application of triazole chemicals and late applications appeared particularly conducive to DBD development.
- DBD development cannot be ameliorated by modification of storage conditions and conversely storage at lower than recommended temperatures was found to aggravate the problem.
- There appears to be no influence of fruit mineral composition on DBD susceptibility and no influence of post-harvest treatments such as diphenylamine, SmartFresh\textsuperscript{TM} or delayed cooling (Johnson, 2006; 2008a).
- There should be rigorous monitoring of fruit in store and detection of the disorder should invoke immediate marketing.

Action points for growers

- Growers should discuss with their advisers the potential impact of agrochemicals on DBD susceptibility for their particular circumstances.
- Non-triazole fungicides should be used in preference to triazole-based fungicides and the use of ‘Cultar’ should be limited in orchards where there is a history of DBD or where medium to long term storage is required.
- Where disease control is a priority the most appropriate spray regime may include triazole fungicides. In such cases the duration of storage may be curtailed in order to avoid problems with DBD.
- Reduction or avoidance of triazole chemicals in spray programs should be regarded as an interim measure until further work has been done on the effect of...
specific chemicals and on the frequency and timing of spray applications.

**Induced by CA conditions:**

**Internal carbon dioxide injury ("brownheart")**

- As the name implies internal carbon dioxide injury is normally associated with abnormally high concentrations of carbon dioxide in the storage atmosphere.
- Adherence to storage recommendations that are provided for different cultivars of apple should avoid the problem.
- However, in the absence of DPA treatment, Bramley’s Seedling apples stored in 5% CO₂ + 1% O₂ (5/1) are susceptible to brownheart and it is necessary to delay establishment of CA conditions until 10 days after loading is complete.
- Where SmartFresh™ is used prior to 5/1 storage the delay should be extended to 21 days.
- Similarly it is important to ensure that carbon dioxide concentrations are 1% or less when low oxygen conditions (1.2% O₂) are first established in Cox stores.
- It is important to operate Cox stores at 2% O₂ for at least a week prior to lowering to 1 or 1.2% O₂ in order to reduce respiration rate (and CO₂ concentration inside the fruit).
- Carbon dioxide injury often begins in the vascular tissue and then extends to include large areas of the cortical tissue.
- Injured areas have a moist, rubbery texture at first but eventually the injured tissue dries out and ‘cork-like’ cavities appear.

**Core flush**

- Core flush is a pink or brown discoloration of the core of apples.
- It occurs late in the storage period and is aggravated by increased carbon dioxide in the storage atmosphere and by lower storage temperatures.
- Cultivars vary in their susceptibility to the disorder. In the UK Cox’s Orange Pippin, Bramley’s Seedling and Braeburn are regarded as highly susceptible although application of best practice as regards the use of appropriate storage conditions, avoidance of over-storage and prompt marketing of fruit after storage generally ensure that core flush is not a commercial problem.
- Storage of Cox apples in the virtual absence of carbon dioxide, and in low oxygen conditions provides good control of the disorder.
- Generally core flush is aggravated by early harvesting, unduly high water loss in store and cool summer temperatures.
- The use of SmartFresh™ aggravates core flush in some cultivars of apple. Core flush development limits the storage life of SmartFresh™-treated Cox stored in CA and excludes the use of SmartFresh™ on Braeburn.

**Induced by mineral deficiencies pre-harvest**

**Bitter pit**

- Bitter pit is probably the disorder that is most familiar to apple growers, both in the UK and abroad, and is of major economic importance.
- Symptoms appear as roughly spherical brown lesions in the flesh of the fruit.
- The pits are dry in appearance and occur mostly just below the skin but in severe cases may affect the entire cortex.
- Bitter pit susceptibility is linked with critical levels of calcium in the tissue and the more frequent occurrence at the calyx end of the fruit relates to the low calcium status of this region.
- Although symptoms of bitter pit may be seen on the tree generally the disorder develops progressively in store.
- Consignments of fruit with inadequate calcium as evidenced by fruit analysis should be sold immediately or stored for short periods.
- Orchards should be managed in a way that ensures adequate calcium uptake and retention by the developing fruit.
- It is important to avoid irregular and excessive vegetative growth.
- Heavy use of potassium and nitrogen fertiliser should be avoided and a comprehensive programme of calcium sprays is recommended for susceptible cultivars.
- Under UK conditions Bramley’s Seedling, Cox’s Orange Pippin and Egremont Russet are particularly susceptible to bitter pit.
- Meridian and Red Pippin are also susceptible whereas the disorder is rarely seen in Braeburn and Jonagold and has not been reported in Gala.
- Although bitter pit is essentially an orchard condition the development of symptoms after harvest is influenced markedly by the conditions under which the fruit is stored.
- Prompt cooling, lower storage temperatures and more stringent CA conditions retard bitter pit development and may be partly curative.
- These effects are taken into account when setting mineral analysis standards.
Late storage corking

- This disorder of Cox apples is usually apparent only after 6 months storage in 1.2% oxygen.
- The lesions are 'corky' in appearance and have similarities with bitter pit.
- However, late storage corking is more extensive and, unlike bitter pit, occurs predominantly in the region between the stem end and the equator of the fruit.
- The disorder is progressive in storage and may increase significantly during distribution and marketing particularly at ambient temperatures.
- Emphasis for prevention of the disorder is placed on pre-harvest factors.
- An imbalance of potassium to calcium in the fruit at harvest has proved to be of major importance. Consequently, fruit for long-term storage in 1.2% oxygen should contain more than 5 mg 100g\(^{-1}\) of calcium and less than 150 mg 100g\(^{-1}\) of potassium.

Water core

- Water core occurs in fruit on the tree and therefore is not strictly a storage disorder.
- It usually becomes less severe during storage and symptoms may disappear entirely.
- However, water core symptoms may be present in fruit removed from store at which time water core breakdown may also be present (see above - water core breakdown).
- Water core is described as a 'glassy' appearance of the apple flesh caused by the presence of sap in the intercellular spaces.
- Analysis of apples affected by water core showed that concentrations of calcium were very low (<4 mg 100g\(^{-1}\)) and therefore occurrences of this disorder in the orchard indicate that other calcium-dependent disorders, such as bitter pit and senescent breakdown, are likely to develop during storage.
- Control measures for water core are similar to those described for bitter pit (see above).

Internal corking

- Internal corking disorders of apple may have some similarities with bitter pit but are associated with boron deficiency.
- Internal cork always affects the core area, and in seriously affected fruit, part or most of the flesh will be affected.
- When the flesh is affected brown, corky, diffuse streaks or wedge-like areas extend from the core into the flesh.
- Although it has been stated that boron deficiency symptoms are unknown in apples grown in the UK, it is probably more common.
As the name implies there are certain cultivars of apple that develop a browning of the skin when the fruit is over-stored.

Generally this type of scald should not be a problem where storage recommendations are adhered to.

Gala is susceptible to senescent scald late in the storage period.

The problem is aggravated by late harvesting, poor control of storage conditions, over-storage and delayed marketing.

DPA is unlikely to provide control of the problem.

Susceptible cultivars (Fiesta (Red Rippin), Gala and Jonagold) required for long storage should be stored in CA conditions with a relatively high carbon dioxide content.

Lenticel blotch pit

- Lenticel blotch pit is a disorder that is related closely to bitter pit.

- Brown lesions form in each "pit" beginning at a lenticel.

- Bramley, Cox and Egremont Russet apples are particularly prone to the disorder that occurs in fruit with abnormally low levels of calcium.

- Consignments of Cox apples containing more than 3.8 mg 100g\(^{-1}\) fresh weight of calcium are unlikely to develop lenticel blotch pit.

- Fruit analysis should be used to determine risk.

- Control measures are the same as those described for bitter pit.

Skin necrosis in Gala apples

- A skin disorder has been observed on Gala apples stored under commercial conditions in the UK.

- The problem occurs rarely and has only been observed on fruit that has been harvested very late and kept in air storage.

- The problem has not been apparent on CA-stored fruit or in air-stored fruit picked at the correct stage of maturity and held at the recommended storage temperature for the prescribed period.

- Mineral composition of affected and non-affected apples was similar.

- Provided that growers adhere to guidelines provided on harvest dates and storage recommendations this disorder should not be a problem in commercial consignments of Gala.

Induced by CA conditions:

External carbon dioxide injury

- This form of damage never occurs in air-stored apples and is not common in apples stored under CA conditions in the UK.

- Generally carbon dioxide injury occurs when fruit is kept in atmospheres containing carbon dioxide at higher than recommended concentrations.

- In the early stages of development damage symptoms may be confused with those of superficial scald.

- However, lesions caused by excessive carbon dioxide are more sharply defined than those described for scald.

- Moreover, external carbon dioxide injury occurs within the first few weeks of storage and does not progress thereafter.

- In contrast, superficial scald usually develops after several months and becomes progressively worse with time in store.

- Bramley’s Seedling apples are susceptible to external carbon dioxide injury under recommended CA conditions.

- Fortunately DPA applied for scald control also prevents carbon dioxide injury.

- Where DPA treatment is omitted it is important that the establishment of CA conditions is delayed in order to prevent injury to the fruit.

- Where SmartFresh\textsuperscript{TM} is applied to Bramley not treated with DPA the delay before establishing CA conditions must be extended further.

- Empire, a cultivar not widely grown in the UK, is highly susceptible to external carbon dioxide injury particularly when treated with SmartFresh\textsuperscript{TM}.

Low oxygen injury

- Injuries to the skin of apples due to low-oxygen storage are generally not recognised on apples grown in the UK.

- In other growing regions low-oxygen injury is expressed in the form of darkening of the red and green regions of the skin.

- Ribbon scald may also be induced in some varieties by low-oxygen atmospheres. McIntosh is considered the most sensitive to this type of injury.

- The risk of low-oxygen injury is minimised by picking at the correct stage of maturity, establishing storage conditions promptly and maintaining CA conditions within prescribed limits.
Induced by chemicals:

**Post-harvest DPA application**
- In the UK diphenylamine (DPA) applied as a dip or drench treatment is used to control superficial scald on Bramley's Seedling apples.
- In other apple growing regions of the world DPA is used widely on a number of dessert cultivars for scald prevention.
- Damaging concentrations of DPA occur where liquid is allowed to accumulate or where there are slow drying conditions in bulk containers.
- Symptoms may appear as small black spots or as a grey/black stain of the skin.
- In the most severe cases of injury extensive areas of the skin become blackened and sunken. The latter symptoms are likely to occur on fruit at the base of treated bins that remain in contact with the solution.
- DPA can cause injury to the core area in Bramley apples that have an open calyx tube.
- In wet harvests internal damage caused by DPA may provide a site for infection by fungal pathogens such as *Mucor* spp.
- In such years it is particularly important to maintain hygienic conditions by changing the solution in accordance with manufacturer’s instructions. This practice also ensures the most efficacious treatment for scald control.

**Post-harvest calcium application**
- The concentration of calcium in apple fruits can be increased by post-harvest application of calcium chloride and proprietary formulations containing calcium.
- Such treatment reduces susceptibility of apples to calcium-dependent disorders such as bitter pit and senescent breakdown.
- Higher application rates result in greater uptake of calcium but there is a corresponding increase in the risk of injury to the fruit.
- The injury is usually centred on lenticels although in severe cases entire areas of skin may be affected.
- The areas around the lenticels become brown or black and may become sunken.
- There may be localised greening of the skin related to the localised uptake of calcium.
- There is marked varietal variation in susceptibility to calcium injury.
- It is important therefore to treat only those cultivars advised by the manufacturers and to apply materials in strict accordance with label instructions.
- Pre-harvest sprays containing calcium may also cause lenticel injury to the fruit.
- Damage symptoms from calcium sprays are generally similar to those described for post-harvest treatments although early sprays can result in distortion of the fruit of sensitive cultivars.

**Early season fruitlet analysis**

There are important advantages in being able to make a prediction of storage quality early in fruit development as opposed to harvest time. Early prediction allows growers more time to plan and organise their storage and marketing schedule and, where possible, apply remedial measures to correct specific nutrient deficiencies.

Previous studies on Cox showed that the ability to predict ex-store firmness or storage disorders such as bitter pit based on mineral analysis alone declined when samples were analysed in mid-July or early August as opposed to late August or at harvest.

However, recent work has indicated the possibility of predicting mineral concentrations in the fruit at harvest on the basis of fruitlet composition and weight and an expected weight of fruit at harvest. Good correlations have been achieved for fruitlet calcium and bitter pit development under New Zealand conditions.

In the North America ‘Fruitlet Guide’ ranges are provided with test results for early season fruitlet analysis so that growers can diagnose deficiencies relatively early in the growing season. However, this programme recommends a further analysis of fruit just prior to harvest. These predictions are based on the general inverse relationship between mean weight per apple and mean calcium concentration.

There is insufficient storage quality and mineral analysis data to establish mineral threshold concentrations for cultivars such as Gala and Braeburn that are increasingly important in UK production. Experiments to provide this information would need to be extended over a number of years in order to allow for the marked seasonal effects on storage quality.

**Predicting storage potential of apples using fruit mineral analysis**

Make an assessment of the storage potential of Cox and Bramley apples from all orchards intended for storage by the use of mineral analysis.

**Sampling**

Samples should be taken at random in the orchard from at least 20 trees usually by following a zig-zag path and taking one apple at random from alternate sides of successive trees.
- Place the 20 apples in a clean polythene bag and label clearly to indicate cultivar, orchard, farm and sampling date.
- If areas of the orchard have been managed differently, for example as regards soil or tree management or there are areas differing in terms of growth and cropping, then these should be sampled separately.
- It may be necessary to segregate sections of the orchard at picking time and to allocate the fruit to different stores based on the indicated storage potential.
Early season analysis

It is possible to make a preliminary prediction of storage disorders based on fruitlet analysis and on the fruit size that is predicted at harvest. Advice is normally available from those providing the analytical service for fruitlets. It is not possible to draw up definitive analysis standards for fruitlets similar to those provided for fruit sampled at or just prior to harvest.

Samples of developing fruit should be taken early in the season e.g. early-mid July to predict the likely achievement of the desired mineral composition at harvest and the need for the application of nutrient sprays to increase the concentration of important elements such as phosphorus and calcium.

Data bases exist for Bramley and Cox which could be used to generate mineral standards for fruitlets in mid-July that relate to recommended standards for harvest fruit. These data relate to the same orchards sampled over a 7-year (Cox) or 9-year (Bramley) period that may provide more precise prediction than commercial data currently being used for this purpose.

Further statistical analysis of the survey data for Bramley and Cox is warranted in order to evaluate the predictive ability of models based on fruitlet (mid-July) or fruit (harvest) analysis.

Pre-harvest analysis

Further sampling for analysis is required at or just prior to harvest to check fruit size (mean fruit weight) and any categorisation of storage potential made earlier in the season.

Sample fruit from Cox and Bramley orchards at harvest or up to 2 weeks prior to harvest.

Compare the analysis results with the recommended standards (see Tables 1 and 2).

Table 1. Harvest mineral composition standards for Cox’s Orange Pippin apples grown in the UK

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>K/Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg per 100 g fresh weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50-70</td>
<td>11 min</td>
<td>130-160</td>
<td>5, 4.5</td>
<td>5</td>
<td>30, 35 max</td>
</tr>
</tbody>
</table>

* a - maximum of 150 mg per 100 g for storage in 1.2% O2 (<1% CO2) later than January
* b - minimum for storage in 2% O2 (<1% CO2)
* c - minimum for storage in air until the middle of October and 1.2% O2 (<1% CO2) later than January
* d, e - maximum for storage in air and CA respectively. Commercially significant losses from bitter pit and late storage corking are likely at larger K/Ca ratios.

Table 2. Harvest mineral composition standards for Bramley’s Seedling apples grown in the UK

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg per 100 g fresh weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60 max</td>
<td>9 min</td>
<td>105-115</td>
<td>5, 4.5</td>
<td>5</td>
</tr>
</tbody>
</table>

* a - minimum for storage in ventilated CA conditions of 8-10% CO2. Calcium requirement is likely to be lower for fruit stored in scrubbed low oxygen conditions of 6% CO2 + 2% O2 and particularly in 5% CO2 + 1% O2 although no definitive level has been set. In the interim a minimum level of 4 mg of calcium per 100 g is suggested.
* b - minimum for storage in air until November.

At harvest

* Samples (20 fruit per orchard) at harvest can be taken directly from the bins prior to loading into store.
* The sampling method should be similar to that described for taking samples for monitoring quality during the storage period.
Standards for Cox's Orange Pippin and Bramley's Seedling apples

Comprehensive survey experiments carried out over many years at East Malling resulted in the development of robust standards for Cox and Bramley (Tables 1 and 2).

- Compliance with these standards is likely to minimise the occurrence of physiological disorders during storage. It is prudent to assign greater storage potential to consignments that exceed the minimum requirements for phosphorus and calcium.

Standards for cultivars other than Cox and Bramley

- It may not be appropriate to apply the mineral composition standards for Cox and Bramley to other apple cultivars although the calcium threshold for bitter pit of 5 mg per 100 g fresh weight appears to be generally applicable.
- Concentrations of N, P, K and Mg are lower in Crispin, Golden Delicious, Spartan and Kent than in Cox and concentrations of P and K in Red Pippin, Gala and Jonagold are low compared with Cox.
- Although lower concentrations of P and K can lead to breakdown in Cox and Bramley apples, they appear to have no adverse effects on the development of disorders in other cultivars.
- The use of Cox standards for P and K for other dessert cultivars could exclude a large proportion of the crop from long-term storage and attempts to raise nutrient concentrations may result in no improvement in storage potential and in some cases storage quality may be compromised. For example, in Gala apples recent evidence suggests that any increase in K concentration may lower firmness and increase flesh breakdown.

Table 3. Average nutrient concentrations in Gala apples (sampled at harvest)

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Mg</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>mg per 100g fresh weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gala</td>
<td>42</td>
<td>9.3</td>
<td>122</td>
<td>5</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Notes:
- Gala is naturally low in P compared to Cox but this does not affect storage potential
- Gala is high in Ca and does not suffer from Ca-dependent storage disorders
- High K fruit may have an increased risk of breakdown
- Fruits higher in Ca and lower in K may be firmer ex-store

Table 4. Average nutrient concentrations in Gala and Braeburn apples (sampled two weeks prior to harvest)

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Mg</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>mg per 100g fresh weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gala</td>
<td>45</td>
<td>10.2</td>
<td>106</td>
<td>5.3</td>
<td>9.6</td>
</tr>
<tr>
<td>Braeburn</td>
<td>52</td>
<td>11.9</td>
<td>102</td>
<td>5.1</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Notes:
- Braeburn similar composition to Cox except that K concentrations appear lower
- Suggest using Cox Ca threshold concentrations to judge storage potential of Braeburn apples

Introduction

It is increasingly difficult for UK growers to make a profit from their apple crop. Many factors contribute to this situation. It is clear that the future of the UK apple industry is dependent on the production of fruit with the quality characteristics demanded by the consumer. Moreover, in the future, the industry will need to respond to inevitable changes in consumer requirements. The information provided in this part of the Guide should help growers to provide UK consumers with fruit of the highest quality over the longest period possible.

This part of the Guide is divided into a number of sections, each concerned with a key area in the attainment of quality fruit to the consumer. The order of the sections reflects the biology of the apple through its phases of development from cell division through to maturity on the tree and finally to ripening and senescence changes that take place during and after storage. The factors that affect storage potential and eating quality are indicated for each phase of development. At any point, failure to adopt best practice can compromise the quality of fruit from store.
Good orchard management is crucial to achieve high yields of large fruit without compromising eating quality or storage potential. It is particularly important to achieve the correct mineral balance in the fruit, especially in Cox and Braeburn and an accurate prediction of storage quality that helps implement a storage and marketing strategy. Picking at the correct stage of maturity for the intended market is probably the single most critical factor affecting quality to the consumer.

Care must be taken with the physical harvesting of fruits and their handling prior to placement in the cold stores. Fruit quality can be lost through bad picking and handling practice and the wastage in stored fruit may be unacceptable where post-harvest chemical treatments are not applied correctly.

It is important to follow strategies for improving quality of stored apples by reducing ethylene production and improving flavour. The SmartFresh® Quality System is being used increasingly within the UK apple industry to supplement existing best practice.

It is critical to maintain storage conditions that are most appropriate for each cultivar and for the duration of storage required. Stores must be capable of achieving the holding temperature and controlled atmosphere conditions within the limits prescribed.

Careful monitoring of the quality of each consignment of fruit in each store needs to be carried out regularly. This will ensure that fruit is removed from store before it declines to the minimum quality required and before any development of disorders or diseases reaches a commercially significant level. Monitoring of fruit condition and identification of the major storage disorders affecting UK apples are described in the Guide, along with post-storage grading, packing and distribution of fruit to the wholesaler or retailer.

Storage facilities and operation

The engineering aspects of storage are not covered in this Guide. The decision to exclude engineering was based mainly on the variability in store construction and in ancillary and control equipment that exists in the UK.

It would be impossible to suggest best practice for the maintenance and operation of stores that vary so much in age, construction, refrigeration plant, coolers, scrubbers, instruments and atmosphere control systems. Moreover modern storage and ancillary equipment has become more complicated and generally requires appropriately trained service engineers to carry out maintenance and rectify problems.

For the purposes of this Guide it is assumed that the stores being used meet the requirements to cool fruit promptly and to maintain temperature and CA conditions accurately. Where these requirements cannot be fulfilled the duration of storage must be adjusted accordingly or the storage facilities must be improved.

In recognition of the range in capabilities within the UK industry, particularly as regards the level of gas-tightness of stores for CA, a range of possible CA conditions is provided wherever possible.

Store operators should also be aware of the information provided in the DVD entitled ‘Operators guide to Top Fruit Management’ that was issued by the HDC in 2006.

Stores in the UK that are used for the storage of apples range in capability from very poor to good. Taken as a whole, for the national stock of apple stores, the average age is high and the average condition is mediocre.

Additionally, the operation of many of the stores is less than ideal, particularly around loading time, with the result that fruit quality is compromised. In many instances, often through lack of appropriate training, the operators and often their managers do not appreciate the significance to ultimate fruit quality of such matters as pre-cooling of stores, slow loading, slow cooling, or deviation from the recommended storage conditions for the specific cultivars. Also, many of the rooms are used for CA storage when they are not sufficiently gas-tight.

For the best practice contained in the post-harvest section of this Guide to be put to maximum effect in providing consistently high quality fruit from store, the stores must operate efficiently.

Growers must diligently record the performance of the store as regards temperature pull-down, temperature variation within the store, control of carbon dioxide and oxygen concentrations and weight (water) loss in the fruit.

Where a store under-performs this should be discussed with an appropriate technical expert to resolve the problems. This should be done as soon as the problems/shortcomings are recognised and remedial action taken prior to the next season.

Likewise at this time preventative maintenance schedules must be in place. It is particularly important that the question of gas-tightness of CA stores is not overlooked.

Growers often have maintenance contracts for their refrigeration plant, ancillary equipment and instruments but may overlook the vital need to check gas-tightness. It is important to test stores scheduled for CA operation for gas-tightness every season.

It is particularly important that operators of fruit stores receive adequate training in the following aspects:

- Store construction
- Monitoring and controlling store conditions
- Refrigeration
- Scrubbing systems and gas generators
- Pre-season checking and maintenance
- Store loading and routine operation

It is also helpful for fruit store operators to have some knowledge of fruit behaviour so that they can associate store performance with the quality of fruit. The HDC DVD entitled ‘Operators guide to Top Fruit Management’ issued in 2006 is particularly helpful in this regard.

Strategies of maintaining flavour in stored fruits

Controlled atmosphere (CA) storage delays ripening and senescence changes in apples and preserves many important quality attributes such as firmness, acidity and soluble solids (sugar) concentration. However, one negative consequence of the use of CA storage for prolonged periods is the reduced production of compounds that contribute to aroma and flavour.

In order to increase the flavour of Cox apples:

- Harvesting should not be earlier than is necessary to achieve the period of storage that is required. Delay in harvesting maximises flavour potential, but harvesting too late reduces storage life and has adverse effects on fruit texture.
- Reserve the use of ultra-low oxygen or ULO (1.2% O₂) for medium or long-term storage provided that the firmness of fruit stored short-term is adequate for the requirements of the market.
- Raise the oxygen concentration in ULO stores to 2% O₂ 4-5 weeks prior to opening the store provided that firmness is adequate for the requirements of the market.
- Practices to maximise flavour in stored Cox apples should only be implemented when there is unlikely to be any detrimental effects on other quality parameters. Full knowledge of the condition of the fruit in store is essential in the decision making process which can be achieved by regular store monitoring.
- The advice provided above on conditioning is likely to be appropriate to all dessert cultivars stored in ULO conditions.
**Effect of CA storage on aroma and flavour**

It is difficult to assess the importance of reduction in the aroma quality of apples by the use of prolonged CA storage. A consumer survey of the quality of Cox apples stored in different CA conditions and subsequently held at different temperatures showed them to be equally acceptable, but for different reasons.

It is clear, however, that high aromatic flavour does not compensate for poor texture and CA-stored Cox may be acceptable on the basis of its desirable texture and taste (sugar/acid balance) characteristics despite a much reduced aroma.

Strategies to improve aroma volatile production are therefore limited by the need to retard changes in other important quality attributes. Johnson (1994c) reviewed the prospect of increasing the flavour of Cox apples stored under CA conditions, and the salient points are reported below:

- The lowest of the oxygen concentrations recommended should be used for that proportion of the crop intended for the longest period of storage.
- The method of scrubbing carbon dioxide (activated carbon or hydrated lime scrubbers) from stores maintained at 2% O_{2} and 0.7% CO_{2} had no effect on fruit aroma nor other quality attributes such as fruit texture and background colour. Concerns that activated carbon scrubbers encourage the removal of aroma compounds from the fruit were unfounded.
- Conditioning of the fruit prior to sale by raising the oxygen levels part-way through the storage period from 1.2 to 2.0% O_{2} increased ester (important aroma volatiles) content to a level comparable with continuous 2.0% O_{2}. There may be some loss of instrumental firmness by raising oxygen levels; consequently this should be delayed until 4-5 weeks prior to opening the store. Moreover, this technique should not be practised in a year when firmness in store is marginal or where there is an over-riding necessity to store Cox to its maximum potential.
- Atmospheres generated in modified atmosphere (MA) packs retard ripening and changes in quality in a similar way to CA storage conditions. Although MA packaging provides apples that are generally firmer and more acidic than non-MA packs, they may be less sweet and have less aroma. The acceptability of the fruit will depend greatly on the relative importance that consumers attach to the various quality parameters.
- Some of the consignment variation in aromatic flavour relates to the maturity of the fruit at the time of harvest. The concentration of certain flavour compounds in Cox apples after storage increases with later harvest dates. However, it is also known that growing season and the source of fruit influence ester content.

**Conditioning for other dessert varieties**

Conditioning Cox apples stored in ULO conditions by raising store oxygen concentrations 4-5 weeks before opening the store is effective in enhancing flavour. In Gala apples increasing the store oxygen from 1% O_{2} to ambient (21%) concentrations part way through a 4-month storage period is reported to have increased the emission of some of the volatiles contributing to aroma. No additional losses of firmness, titratable acidity or soluble solids content were detected after storage in ‘dynamic’ conditions.

Recent research has shown potential benefit of enhanced aroma production in CA-stored Fuji and Granny Smith apples by short-term exposure to hypoxic (low oxygen) treatments. The hypoxic treatment (<0.5% O_{2}) applied for 1 day enhanced subsequent ester production possibly by providing ethanal as a precursor for ester synthesis.

1. Further work is required on UK cultivars to compare the effectiveness of hypoxic and anoxic (high oxygen) and ‘dynamic’ treatments for amelioration of low aromas in apples after long-term storage.

Since the distinctive aroma component of Cox apples segregates as though determined by a single dominant gene, it should be possible to breed new selections with improved storage potential and conserved Cox aromatic flavour. Cultivar improvement would reduce the reliance on stringent CA conditions to retard ripening and quality loss during storage with the prospect of enhanced aroma production.

2. More rapid selection techniques are required to screen for flavour and further genetic studies might result in convenient marker genes being identified that can be used as assays for flavour at an early stage.

**Maintaining quality during marketing**

Early season apples intended for direct marketing begin to lose quality immediately after harvest. Likewise apples from CA storage lose quality as soon as the gas seal is broken. In both cases, without sufficient control of produce respiration, the quality of product reaching the consumer may be inadequate to provide satisfaction. This can have an immediate and long-term adverse reaction on the sales of UK fruit.

Much can be done to ensure higher quality product in the market place through an awareness of the benefits of temperature control after harvest (early apples) or after grading (storage cultivars). Following best practice will help to ensure that all the efforts to achieve high quality through application of good husbandry and storage practice are not wasted after fruit leaves the packhouse.

Where cool temperatures cannot be maintained and the period between packing and consumption exceeds 10 days, the use of modified atmosphere (MA) packaging provides useful improvements in product quality. However, it is important that growers discuss the use of MA packaging with their marketing agents and their customers (retailers and wholesalers) to ensure their acceptance in the market place.

It is particularly important that supply of product in retail MA packs is acceptable to retailers that are accustomed to selling the bulk of their product ‘free-flow’. In this regard it may be that the bulk packs (18kg cardboard cases lined with a suitable polymeric film) that preserve quality to the retail shelf are the most appropriate application of MA technology for UK retailers. It is also important for producers to be able to achieve higher prices for their higher quality product in order to meet the additional costs of packaging.

Although the quality benefits of MA packaging are proven for a number of cultivars these are achieved generally at ambient temperatures and over periods in excess of 2 weeks. Where prompt distribution of product occurs at cool temperatures the use of MA techniques may not be justified. Consequently, at the present time the use of MA packaging is not included in best practice.

**Early season apples**

- Keep fruit shaded after picking and during transport from the orchard.
- Ensure fast removal of field heat by loading fruit into store that has been pre-cooled to OCP. Load no more than 10% of the total capacity of the store e.g. a maximum of 10 tonnes of fruit into a 100 tonne store.
- After pre-cooling grade and pack quickly, return packed fruit to a pre-cooled holding store.
- Short journeys in non-insulated transport should be made during the hours of darkness.
- Insulated or refrigerated transport should be used for long or daytime journeys.
- All transfers on and off vehicles should be done rapidly.
- Encourage the use of cool displays at the retail level.
Storage cultivars

- Terminate storage while there is sufficient quality to allow for packing and distribution.
- Keep packed fruit cool, ideally 3.5°C but at below 10°C at least.
- Use chilled distribution where possible.
- Encourage cool display in retail outlets.
- Avoid 'back-storage'.

Growers can use Table 28 to convince marketers and distributors of the need for prompt delivery of their product to the retail shelf and of the importance of maintaining cool temperatures during distribution. These results apply to Cox apples removed from CA storage where the intention is to achieve 6 kg firmness on the retail shelf.

Table 28. Effect of temperature on firmness decline in Cox apples

<table>
<thead>
<tr>
<th>Firmness ex-store (kg)</th>
<th>1.5°C</th>
<th>3.5°C</th>
<th>10°C</th>
<th>18°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.6</td>
<td>30</td>
<td>20</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>6.4</td>
<td>20</td>
<td>13</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>6.2</td>
<td>10</td>
<td>7</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Introduction

The rate of ripening and senescence in apples is retarded primarily by the use of refrigeration and controlled atmosphere (CA) storage. Growers are familiar with the benefits of these techniques in terms of season extension and for maintaining the visual and eating quality of apples, particularly those harvested mid- to late season.

However, control of post-harvest temperature has marked benefits in maintaining the quality of early season apples during distribution and marketing. This is particularly important for cultivars such as Discovery that ripen rapidly and have an inherent short shelf-life and are harvested when high ambient temperatures normally prevail.

Control of post-storage temperature for the main storage cultivars is just as important as for the marketing of early apples. Months of effort in maintaining appropriate storage conditions can be wasted by lack of consideration of the time and temperature that the apples experience after removal from CA and low temperatures.

As apples ripen slowly during storage there will be a corresponding reduction in the expected shelf-life i.e. the time to reach an unacceptable quality. Research has shown that the loss of quality after storage is predictable and this allows a logistics approach to ensure that consumers are provided with consistent quality.

Use of refrigeration

Discovery and other early season apples

Control of post-harvest temperature is just one part of a package of measures that have been devised to regulate the supply of fruit to the market and to ensure that produce reaches the consumer with minimal loss of quality.

- It is necessary to harvest fruit at the correct stage of maturity and to ensure rapid removal of field heat.
- To obtain significant benefits fruit temperature must continue to be controlled during distribution of the fruit to the supermarket depot or wholesale market.
- The rate of softening can be more than halved by holding Discovery apples at 10°C rather than 20°C throughout a 10-day shelf-life period.

Cox’s Orange Pippin

- There was a lot of research done on the effects of post-storage temperature on Cox in order to address the problem of inconsistent eating quality in consignments of apples reaching the market.
- In particular the texture of the fruit was often inadequate to satisfy consumers with a known preference for firm, juicy apples.
- As in the case of Discovery apples, quality loss in Cox at 10°C was approximately half that at 18°C (Table 29). Quality was measured in terms of weight loss, background colour and firmness.
- A more complete account of the affects of temperature on post-storage quality changes in Cox is provided elsewhere.

Table 29 - Average losses (per day) in Cox quality after removal from CA storage

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>Weight Loss (%)</th>
<th>Greenness (Worldwide fruit chart)</th>
<th>Firmness (N) (kg in)</th>
<th>Days from 6.5 kg to 6 kg firmness (projected)</th>
</tr>
</thead>
</table>
studies in commercial orchards average nitrogen levels in the leaves (2.3%) of these cultivars were well below the minimum level recommended for Cox (2.6%).

There have been no trials to evaluate the effect of nitrogen application on other dessert cultivars important in UK production such as Gala and Jonagold. However, in recent

on storage quality. To achieve optimum yields and quality in terms of greenness and least red coloration a minimum leaf N of 2.6% is suggested.

Where effects of grass competition are reduced or removed by the use of herbicide, applied in the tree row or to the entire soil surface, there was little effect of N application

colour and increased redness detracts significantly from the market value.

Leaf nitrogen for Bramley is 2.4-2.8 % (dry weight) and the upper limit for nitrogen in the fruit at harvest is 60 mg 100g

Bramley produces higher yields and more vegetative growth than Cox and consequently has a higher requirement for nitrogen fertiliser (MAFF, 2000). The satisfactory range in

Recent evidence has suggested a positive role for nitrogen in the development of firm Cox apples. Sprays containing calcium nitrate or urea applied during the cell enlargement

For Cox and other dessert apple cultivars the judicious use of nitrogen fertiliser should be considered in order to maximise red colour development.

Use of modified atmosphere (MA) storage

Packaging of apples in semi-permeable films has the effect of modifying the atmosphere surrounding the produce with respect to the concentration of oxygen, carbon dioxide, nitrogen and other volatiles such as ethylene.

- The effects of elevated carbon dioxide and lowered oxygen in modified atmosphere (MA) packs in slowing product deterioration are essentially similar to those achieved using CA storage.
- However, atmosphere conditions generated in MA packs are generally less well controlled than in a CA store. Nevertheless, an MA pack appropriately designed to accommodate respiration differences due to cultivar and variable ambient temperature affords worthwhile improvements in post-harvest or post-storage life.

Retail packs for Discovery

- In packs of Discovery apples sealed with low density polyethylene films (LDPE) equilibrated atmospheres containing 3-5% carbon dioxide and 5-6% oxygen developed within 1-2 days at 20°C.
- Softening and yellowing of the fruit was markedly retarded. Subsequent work showed that the benefit of MA packaging for Discovery apples was reduced when the technique was used for late-picked fruit and the risk of adverse effects such as the development of off-flavours was increased.
- Discovery apples that benefit most from MA packaging are those that are just beginning to ripen at the point of harvest. Discovery apples harvested earlier are endowed with a longer shelf-life and may not benefit from MA packaging over the period allowed for marketing.
- Late-picked Discovery fruits are unlikely to benefit from MA technology and may develop off-flavours unless accompanied by cool chain marketing.
- Further work is required to identify markers of respiration rate that would enable growers to select fruit that would be most suited to MA packaging.

Retail packs for Bramley's Seedling, Cox's Orange Pippin, Egremont Russet and Spartan

- Beneficial effects on the post-storage quality of Bramley, Egremont Russet and Spartan apples were achieved by sealing fruit in LDPE bags of 30 mm thickness for 2-4 weeks at 15°C.
- In Cox, the best results over 2 weeks at 15°C were achieved using a 30 mmethylene vinyl acetate (EVA) film.
- Another development in MA technology was a bulk pack consisting of a 18 kg (40 lb) case of fruit with a sealed permeable liner. LDPE (30 mm) liners produced atmospheres of 7-10% carbon dioxide and 5-7% oxygen for Bramley apples during a 4-week period at ambient (10-20°C) temperatures.
- Micro-perforated LDPE liners were most suitable for Cox apples. Shelf-life improvements with the bulk packs were similar to those achieved using retail (1 kg) packs.

Nitrogen

Where apples are produced in warmer climates than in the UK, there is much concern about the overuse of nitrogen fertiliser. In North America, at harvest, high nitrogen fruit tend to be larger, greener, softer, more subject to pre-harvest drop, and more likely to be affected by cork spot and bitter pit. After storage they develop greater amounts of scald, bitter pit, internal browning and internal breakdown.

In the UK no such dramatic adverse effects on fruit quality have been associated with nitrogen application. Contrary to the results of Bramlage et al., (1980) there are reports that the application of nitrogen fertiliser reduces the susceptibility of Cox apples to bitter pit. However, Richardson (1986) reported softer fruit and a greener background colour in Cox apples following additional application of nitrogen fertiliser.

Upper limits for leaf and fruit N of 2.6% (dry weight) and 70 mg 100g

it is suspected that where nitrogen application is associated with poorer storage quality the effects may be due indirectly to the stimulation of vegetative growth and an increase in fruit size. These effects can alter the concentration of other nutrients in the fruit such as calcium and phosphorus that are more causally linked with the development of physiological disorders during storage.

For Cox and other dessert apple cultivars the judicious use of nitrogen fertiliser should be considered in order to maximise red colour development.

Recent evidence has suggested a positive role for nitrogen in the development of firm Cox apples. Sprays containing calcium nitrate or urea applied during the cell enlargement phase of fruit growth (late June - harvest) have had a positive influence on the texture of Cox apples. Growers should consider using calcium nitrate sprays in preference to calcium chloride for Cox apples (see section on calcium below).

Bramley produces higher yields and more vegetative growth than Cox and consequently has a higher requirement for nitrogen fertiliser (MAFF, 2000). The satisfactory range in leaf nitrogen for Bramley is 2.4-2.6 % (dry weight) and the upper limit for nitrogen in the fruit at harvest is 60 mg 100g

The method of soil management in Bramley orchards is particularly important. Complete grass cover is intensively competitive and dramatically reduces the availability of water to the tree and the uptake of nitrogen. It is difficult to overcome the adverse effects of grass competition on fruit yields by nitrogen application alone.

Where leaf N is below the recommended minimum of 2.4 % (dry weight) the yield and size of fruits is likely to be reduced. In addition the increased yellowing of the background colour and increased redness detracts significantly from the market value.

Where effects of grass competition are reduced or removed by the use of herbicide, applied in the tree row or to the entire soil surface, there was little effect of N application on storage quality. To achieve optimum yields and quality in terms of greenness and least red colouration a minimum leaf N of 2.6% is suggested.

There have been no trials to evaluate the effect of nitrogen application on other dessert cultivars important in UK production such as Gala and Jonagold. However, in recent studies in commercial orchards average nitrogen levels in the leaves (2.3%) of these cultivars were well below the minimum level recommended for Cox (2.6%).
Cox nutrient standards should not necessarily be applied to other dessert cultivars. However, commercial experience (FAST Ltd) with Jonagold indicates a high requirement for nitrogen and that routine top dressings are required to maintain high yields.

**Further research requirements**

Further work is required into the effects of nitrogen fertiliser application on the quality of dessert apples under UK growing conditions. These studies are required particularly for Gala and Braeburn where production continues to increase.

It is important to be able to establish guidelines for nitrogen nutrition in order to maximise cropping potential and profitability of commercial orchards but at the same time safeguarding storage and eating quality.

**Phosphorus**

Achieving levels of phosphorus in Cox and Bramley apples at harvest reduces their susceptibility to low temperature breakdown (LTB) during storage. This is particularly important where climatic conditions during development increase susceptibility to LTB. Fruits that are low in phosphorus also tend to be softer although this may not be a causal association.

Crop load affects the concentration of phosphorus in fruits. Heavier cropping reduces the amount of phosphorus per apple but also restricts the amount of dry matter available to the fruit. It is likely that the shortage of dry matter for cell wall formation is linked to poorer texture rather than the associated depression in phosphorus levels.

Flower and fruit thinning increased firmness and phosphorus concentration in Cox apples. Minimum recommended levels of phosphorus in Cox and Braebury apples are 11 and 9 mg 100g\(^{-1}\) (see Section 3). Minimum recommended levels of phosphorus in the leaves of Cox to achieve good storage quality is 0.24% (dry weight) which is at the high end of the range (0.20-0.25%) recommended for satisfactory yield.

In surveys carried out in the 1980s 90% of commercial Cox orchards achieved target levels for phosphorus in fruit compared with only 68% of Bramley orchards. In the pursuit of even higher yields the proportion of orchards that achieve satisfactory levels of phosphorus is likely to decline. The problem will be exacerbated where soil management is based on the use of herbicides and by increased rates of nitrogen fertiliser.

Phosphorus problems in established orchards are unlikely to be rectified by the application of phosphate fertiliser, as phosphorus is poorly mobile in the soil. Foliar sprays containing phosphorus are recommended for both Cox and Bramley, particularly where there is a history of breakdown during storage and fruit analysis indicates that low fruit phosphorus may be a contributing factor.

Sprays containing phosphorus applied to Cox trees in the period mid-June to September markedly reduced susceptibility to LTB and senescent breakdown. Similar effects of phosphorus sprays were found in Bramley, although only those sprays applied during the period mid-June to mid-July gave effective control of breakdown.

The effect of time of application of phosphorus sprays on the development of LTB in Cox has not been examined critically but it would be advisable for growers to make applications in the period mid-June to mid-July. This advice is supported by the correlation between low phosphorus in fruitlets sampled in July and increased LTB in stored fruit.

There has been no evaluation of the effects of phosphorus sprays on the storage quality of other cultivars of apple important in UK production. Although the concentration of phosphorus in Crispin (Mutsu), Spartan, Red Pippin (Fiesta), Jonagold and Gala apples are much lower than in Cox there is little evidence of LTB problems in commercial storage. Moreover, the storage temperature (CA) for Spartan, Jonagold and Gala is lower than for Cox apples. Attempts to raise the phosphorus levels in these cultivars appear unwarranted.

**Potassium**

Adequate potassium supply to apple trees is essential in order to achieve regular yields of high quality fruit. Potassium is particularly important in ensuring sufficient acidity in apples and for providing the characteristic taste to more acidic cultivars such as Cox.

In the past, with nitrogen, there was a tendency to over-supply trees with potassium fertiliser. It is universally accepted that excessive potassium in the fruit at harvest increases their susceptibility to bitter pit during storage. In Cox, high potassium in leaves and fruits was associated with increased Gloeosporium rot, core flush, lenticel blotch pit and late storage corking.

Although high potassium fruit may be less prone to some forms of breakdown, the adverse effects of excessive potassium generally outweigh any possible beneficial effects. It is particularly important to omit fruit with excessive potassium from long-term storage. However, Cox apples that contain less than the recommended minimum amounts of K should also be omitted from long-term storage due to the possible development of low temperature or senescent breakdown.

Growers need to ensure that leaves and fruits from all orchards are analysed each year in order to determine the requirement for potassium fertiliser. For Cox an upper limit for potassium of 1.6% (dry weight) is advised.

Fruit potassium levels in any particular orchard will vary from year to year and it is important to develop a ‘trend-line’ by regular analysis. Crop load has a major impact on the potassium concentration in the fruit with heavy cropping generally reducing the concentration. Flower or fruit thinning increased fruit potassium levels in Cox and increased their susceptibility to senescent breakdown and core flush during CA storage.

Where cases of severe potassium deficiency occur, foliar sprays of potassium sulphate (10-15 kg 10000 l\(^{-1}\)) can be applied to supplement soil application of fertilisers. Three applications may be made at 14-day intervals starting at petal fall. Sprays containing potassium are not advised for any other purpose, as they are likely to promote the development of bitter pit.

**Calcium**

Calcium is regarded universally as the most important element for the maintenance of post-harvest quality. This applies not only to apple but to a range of other fresh horticultural crops where inadequate supply of calcium during development results in important economic losses.

The concentration of calcium required in apples at harvest to prevent premature senescence and the development of disorders such as bitter pit during storage have been defined for Cox and Bramley. Other physiological disorders associated with low calcium in the fruit include watercore, lenticel blotch pit, late storage corking and senescent breakdown.

Problems with calcium nutrition of apples generally relate to factors that affect the distribution of this element within the tree rather than a lack of uptake through the roots. However, it is advisable that growers ensure that the maximum amount of calcium is available for uptake by the roots in addition to the adoption of methods to supplement calcium nutrition.

It is particularly important to ensure that the acidity of the soil is optimal i.e. a pH level of 6-6.5. On a sandy soil improvement in the concentration of calcium in Cox apples was achieved by liming and by application of calcium sulphate to the soil. There was an additive positive effect of the treatments on fruit calcium concentration.

Calcium concentrations in bulked samples of apples are usually inversely related to the mean weight per apple. Therefore any management practice that increases mean fruit weight is likely to result in a lower concentration of calcium in the fruit. Practices that contribute calcium to the fruit without reducing fruit size need to be encouraged but often
there is a requirement for directly supplementing calcium supply to the fruit by the use of orchard calcium sprays.

The application of calcium sprays should be considered as routine for cultivars such as Cox, Bramley, Egremont Russet and Spartan. Under UK conditions some cultivars, such as Gala, have very high calcium concentrations in the fruit and it is therefore questionable whether calcium sprays are warranted. There are some key points to consider with regard to the efficacy of calcium sprays.

**Calcium salt**

- Calcium chloride is generally the preferred form of calcium for foliar application to UK cultivars. Although it is more likely to cause leaf scorch than the main alternative, calcium nitrate, it is less likely to damage the fruit.
- Calcium chloride may cause unacceptable leaf scorch on Egremont Russet and for this cultivar the use of calcium nitrate is advised.
- Recent research suggests that calcium nitrate sprays are effective in improving the firmness of Cox apples at harvest and during storage and may be preferable to calcium chloride sprays.
- However, the general use of calcium nitrate sprays is not advocated since a number of cultivars have suffered lenticel damage as a result. These include Discovery, Bramley's Seedling, Idared, Laxton's Superb, Spartan, Merton Worcester and Tydeman's Early Worcester.
- Proprietary forms of calcium chloride and other calcium salts are available to UK growers and these should be applied in accordance with manufacturer's instructions. However, it is important that growers ensure that spray programmes based on proprietary products provide an equivalent amount of actual calcium as a ‘standard’ calcium chloride programme (see below).
- Alternatively, where lower rates of commercial products are recommended, evidence should be provided of their greater efficacy.

**Rate of application**

- The major factor that determines the effectiveness of a calcium spray programme is the amount of actual calcium that is applied per hectare during the growing season.
- The minimum amount of calcium chloride flakes (78% calcium chloride) or calcium nitrate prills (79% calcium nitrate) that should be applied during the season is 72 kg and 110 kg hectare\(^{-1}\) respectively regardless of spray volume.
- Low volume (50–100 litres hectare\(^{-1}\)) applications of calcium chloride proved as effective as higher volume applications in raising calcium status and reducing bitter pit in Bramley.
- However, results also showed that no reduction in the amount of calcium chloride applied per hectare was possible at reduced volumes of water. Low volume applications caused minimal leaf scorch and were not injurious to the fruit.

**Timing of sprays**

- Increase in the calcium concentration in the fruit is affected by direct uptake of the spray solution by the fruit. Consequently as the fruits become larger during development there is a larger ‘target’ for the calcium sprays and, therefore, late sprays are generally more effective than early sprays.
- Spraying of early cultivars should commence in early June and for later maturing cultivars in mid-late June. It is important to continue spraying as near to picking as is practicable.
- Early sprays are often reduced to half-strength to avoid damage to young foliage. In this situation provision should be made to increase the frequency of application to ensure that the recommended minimum amount of calcium is applied during the season.
- The same advice applies where the risk of leaf scorch from calcium applied during warm weather (>21°C) necessitates half-strength application. It may not be necessary to be as cautious about spraying in high temperatures when applying calcium chloride in water volumes of 100 litres per hectare or less.

**Magnesium**

The most well known role of magnesium in plants is its occurrence at the centre of the chlorophyll molecule. In addition to this function, inadequate levels of magnesium can inhibit \(\text{CO}_2\) assimilation during photosynthesis. Consequently most of the concerns related to magnesium deficiency are related to aspects of tree growth and cropping.

Although there is little evidence for direct effects of either deficient or excess magnesium on fruit quality in North America, higher levels of magnesium in Cox confer increased resistance to flesh breakdown. Sprays containing MgSO\(_4\) (Epsom salts) reduced flesh breakdown in stored Discovery and Cox apples. However, it is known that a high ratio of magnesium to calcium increases wastage due to bitter pit.

It is advised to supplement magnesium where leaf analysis indicates that levels are sub-optimal or where deficiency symptoms are evident on the foliage. Sprays containing Epsom salts will rectify deficiency more rapidly than soil applied forms of magnesium such as magnesium limestone, kieserite or calcium magnesium (MKM, 2000). Two to five applications of magnesium sulphate (20 kg 1000 \(\text{ha}^{-1}\)) may be necessary, applied at 14-day intervals.

It is important to follow the magnesium sprays with a comprehensive programme of calcium sprays to offset any increased bitter pit potential. Proprietary formulations containing magnesium may be substituted for Epsom salts as appropriate.

**Boron**

Boron is important in ensuring normal tissue development in plants. It is important in the development of the fine structure of cell walls, in facilitating sugar translocation and in the synthesis of nucleic acids.

In apple, boron deficiency causes internal and external cork development and is of frequent occurrence in orchards in North America. In the UK, boron deficiency in apples is quite rare and is associated with boron concentrations in the fruit of less than 0.1 mg 100g\(^{-1}\) fresh weight giving rise to internal corking symptoms.

Whilst it is important to ensure that apple trees receive sufficient boron, excessive levels can cause earlier maturation of the fruit and increased incidence of water core at harvest and may promote the development of internal breakdown and decay in stored fruit.

There is evidence that a single ‘Solubor’ (Boran Consolidated Ltd) spray at petal fall or 2-4 weeks later reduces skin cracking in Egremont Russet and in some orchards of Cox. There was also some indication that boron sprays could provide some measure of control of bitter pit on Egremont Russet. In other trials, ‘Solubor’ sprays applied to Discovery and Cox trees enhanced red colour development on the fruit but increased the incidence of skin cracking and flesh breakdown during storage.
Surveys of Cox and Bramley orchards have indicated that very few are marginal or deficient in boron. In view of the potential adverse effects of excess boron in the fruit, it is advised that growers arrange for an analysis of leaves and fruits in orchards where boron deficiency is suspected.

Boron deficiency can be corrected by soil application of borax (20 kg ha\(^{-1}\)) or ‘Solubor’ (10 kg ha\(^{-1}\)) in the spring. However, the relative immobility of boron in plants favours the use of foliar sprays as a means of correcting deficiency.

Recent work on Bramley showed that autumn sprays of boron were most effective in increasing boron in the flowers that developed in the following spring. Applications made at full bloom had no effect on flower boron concentrations but sprays applied during cell division increased the boron status of spur leaves (June) and of the fruit (July and harvest).

This work tends to confirm advice to apply 3 sprays of ‘Solubor’ (2 kg 1000 l\(^{-1}\) ha\(^{-1}\)), with an appropriate wetter, starting at petal fall and repeated at 2-3 week intervals (MAFF 2000). Other proprietary boron formulations can be substituted for ‘Solubor’ as appropriate.

### Optimal storage conditions

#### Pre-cooling

Pre-cooling is the term used to describe the extraction of field heat from the crops prior to storage. The advantages of pre-cooling are the rapid cooling of produce to storage temperature and a reduced demand on the main store cooling capacity.

- Forced air-cooling uses the principle that the rate of heat transfer from product to air increases with increasing air speed.
- With this technique a high-speed current of cold air is directed on to the product.
- It is possible to adapt most apple stores for use as forced air coolers using a plenum or tarpaulin sheet.
- The practice of leaving fruit out over night to cool should be avoided.
- On cold nights in September the air is usually still such there is no air movement around the fruit and thus very little cooling effect.
- The old night air does increase the efficiency of the condenser and thereby increases the rate that heat can be transferred from the product to the outside air.

#### Duration of storage and storage conditions

Generally, the longer that fruit are held in store the more susceptible they become to rotting by fungi and superficial scald and calcium-dependent disorders such as bitter pit. It is particularly important to avoid storing fruit to the point where their resistance to rotting is lowered.

- It is important to market fruit within the periods suggested for any particular storage condition and to monitor fruit regularly in order to gain advance warning of significant rot development or deterioration in fruit quality.
- CA conditions will not prevent infection of fruit in store although the composition of the atmosphere can influence the degree of rotting in store.
- In Cox, CA conditions that are low in oxygen and high in carbon dioxide are more conducive to rotting than low oxygen only. Growers should ensure that Cox apples for medium or long-term storage are kept in low oxygen/low carbon dioxide conditions particularly where there is a history of rot problems.
- Fruit harvested from Bramley orchards seriously affected by Nectria canker should not be stored in 5% CO\(_2\) + 1% O\(_2\) (5/1) due to an aggravated development of Nectria fruit rots.

Ensure that the most appropriate conditions are used for the period of storage that is anticipated. Termination dates that are recommended should be a guide only since the quality of consignments in store is likely to vary from orchard to orchard and from season to season.

Optimal quality can only be achieved by ensuring that consignments have adequate storage potential with respect to mineral composition and maturity at harvest.

Careful monitoring of fruit condition throughout the storage period is required to ensure that quality retention is in line with expectations. Those responsible for the storage of fruit should be fully aware of the notes that are included in the recommendations issued by East Malling Research (EMR) since these may be vital in achieving a successful outcome.

Information provided in this Section should be consistent with that provided in a wall chart (‘UK Storage Recommendations for Tree Fruit’) produced by the HDC and distributed to all registered growers in 2008. It is difficult to set precise termination dates for the storage of any cultivar, as there are so many variables involved. Provided the fruit has adequate storage potential, the termination dates that are advised should result in quality product. It is essential that:

- Stores are loaded in 2-3 days and the operating temperatures are achieved within 5 days of the start of loading.
- The delay between picking and the start of cooling does not exceed 24 hours.
- Final CA conditions are achieved within 14 days of the start of loading unless indicated otherwise.

Independent checks of store CO\(_2\) and O\(_2\) levels should be made regularly using portable analysers and drawing atmosphere sample direct from the store.

### Storage conditions recommended for major apple cultivars in the UK

The latest recommended conditions for the storage of the major apple cultivars and some of the more popular traditional cultivars grown in the UK are provided in the tables below.

Recommendations for the major cultivars are generally unchanged from those published by Johnson in 1998(a) and in the previous version of the Best Practice Guide for UK Apple Production. However, advice is given for the first time on the storage of 'Club' cultivars such as Jazz, Kanzi and Rubens, in some cases based on experience abroad.

Growers that require information on other traditional cultivars should refer to earlier recommendations (Sharples and Stow, 1986). However, it should be borne in mind that these older recommendations relate to an era when quality requirements differed significantly from those demanded currently by retailers and consumers.

Current emphasis is on achieving a high standard of eating quality in addition to high visual quality and freedom from diseases and disorders. Formerly the provision of sound fruit from storage was the primary objective with a heavy reliance on variety name as a selling point in the market.

Consequently the use of older recommendations may not provide fruit of suitable quality for the period of time indicated. It is relatively recently that storage in oxygen concentrations below 2% ('ultra-low oxygen') has become widely practised.

More recently recommendations based on elevated levels of carbon dioxide in combination with 'ultra-low oxygen' have been introduced. Only current commercial cultivars have been tested under these stringent CA regimes.

The industry should follow future research developments very carefully.
Braeburn and clones

The storage conditions provided for Braeburn in Table 9 were established after a 3-year HDC-funded project (TF 152). However, further research on the storage of Braeburn is on-going and will be completed in the spring of 2009 (HDC-funded project TF 175).

In the first year of project TF 175 a three-fold reduction in core flush was achieved by sealing CA stores immediately after loading and there were quality benefits from storing in oxygen levels lower than currently recommended.

Table 9 - Recommended storage conditions for Braeburn and clones

<table>
<thead>
<tr>
<th>Air storage</th>
<th>With SmartFresh™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
<td>Terminate (month)</td>
</tr>
<tr>
<td>0 - 0.5</td>
<td>December</td>
</tr>
<tr>
<td></td>
<td>Do not use</td>
</tr>
</tbody>
</table>

Controlled atmosphere – Using a scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>%O₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 - 2.0</td>
<td>&lt;1</td>
<td>2</td>
<td>Early March</td>
<td>1, 2, 3</td>
<td>Do not use</td>
<td></td>
</tr>
</tbody>
</table>

*Do not use elevated CO₂ only (un-scrubbed CA).*

**Notes:**

1. It is advised (Washington State, USA) to delay the sealing of CA stores for 3 weeks from the completion of loading to avoid Braeburn browning disorder (BBD).
2. CO₂ concentrations should be maintained below 1% to reduce the risk of BBD.
3. Ensure that O₂ level does not fall below 1.7% when controlling manually at 2% O₂, aim to keep a mean of 2%.

Bramley’s Seedling

Table 10 - Recommended storage conditions for Bramley’s Seedling

<table>
<thead>
<tr>
<th>Air storage</th>
<th>With SmartFresh™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
<td>Terminate (month)</td>
</tr>
<tr>
<td></td>
<td>Terminate (month)</td>
</tr>
<tr>
<td></td>
<td>Notes</td>
</tr>
</tbody>
</table>
### Controlled atmosphere – No scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 - 4.5</td>
<td>8-10</td>
<td>June</td>
<td>1, 2, 3</td>
<td>March</td>
<td>8, 9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Controlled atmosphere – Using a scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>%O₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>%O₂</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0 - 4.5</td>
<td>6</td>
<td>2</td>
<td>June</td>
<td>1, 2, 4, 5</td>
<td>Few results</td>
<td>8, 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
<td>July</td>
<td>1, 2, 4, 6, 7</td>
<td>July</td>
<td>8, 10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

1. Use post-harvest chemical treatment to control superficial scald. Where fruit is to be stored short-term without DPA treatment then establishment of CA conditions should be delayed (see 6 below) in order to avoid possible CO₂ injury.

2. Slight risk of low temperature breakdown in fruit stored beyond May, especially if late-picked or fruit phosphorus is below 9 mg 100g⁻¹.

3. Use scrubbed storage for Bramley to improve control of bitter pit.

4. Ensure that the recommended CO₂ level is not exceeded by more than 0.5%.

5. Ensure that O₂ level does not fall below 1.7% when controlling manually at 2% O₂, aim to keep a mean of 2%.

6. Use diphenylamine (DPA) post-harvest to prevent possible injurious effects of this CA regime. Alternatively, for fruit not treated with DPA, delay the sealing of the store by 10 days from the completion of loading. Where nitrogen flushing is used to achieve low oxygen conditions extend the delay to 15 days. Where fruit is to be stored beyond March use half the recommended rate (1000 ppm) of DPA to control superficial scald.

7. For operation at 1% O₂ use automatic equipment to control O₂ within the range 0.9-1.1%.

8. If SmartFresh™ is used wait 21 days before sealing CA stores. Do not allow any build-up of CO₂ during this period. After 21 days establish CA conditions as soon as possible.

9. Longer storage possible if DPA used to control scald.

10. Scrubbed stores may be sealed after loading and O₂ levels allowed to decline to 10% during the 3 weeks after SmartFresh™ application.

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**Cameo**

**Table 11 - Recommended storage conditions for Cameo**

| Air storage | With SmartFresh™ |
Controlled atmosphere – Using a scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>% CO₂</th>
<th>% O₂</th>
<th>Terminate (month)</th>
<th>Notes</th>
<th>Terminate (month)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 - 2.0</td>
<td>&lt;1</td>
<td>1.5</td>
<td>June</td>
<td>1</td>
<td>June</td>
<td>2</td>
</tr>
</tbody>
</table>

Only limited research has been carried out on Cameo in the UK. Recommendations are based on commercial experience in the UK. There are no recommendations for storage in elevated CO₂ (un-scrubbed) only.

Notes:
1. For operation at 1.5% O₂ use automatic equipment to control O₂ within the range 1.4-1.6%.
2. Better flavour reported.

Cox’s Orange Pippin and clones

Table 12 - Recommended storage conditions for Cox’s Orange Pippin and clones

<table>
<thead>
<tr>
<th>Air storage</th>
<th>With SmartFresh™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
<td>Terminate (month)</td>
</tr>
<tr>
<td>1.5 - 2.0</td>
<td>Mid October</td>
</tr>
</tbody>
</table>

Controlled atmosphere – No scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>% CO₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
</table>
Controlled atmosphere – Using a scrubber

With SmartFresh™

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>%O₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 - 4.0</td>
<td>5</td>
<td>3</td>
<td>Late Jan</td>
<td>1, 2</td>
<td>January</td>
<td>8, 9</td>
</tr>
<tr>
<td>&lt;1</td>
<td>2</td>
<td>3</td>
<td>Late Feb</td>
<td>3</td>
<td>January</td>
<td>8, 9</td>
</tr>
<tr>
<td>&lt;1</td>
<td>1.2</td>
<td>3</td>
<td>Late March</td>
<td>4, 5, 6, 7</td>
<td>January</td>
<td>8, 9</td>
</tr>
</tbody>
</table>

Notes:
1. Ensure that the recommended CO₂ level is not exceeded by more than 0.5%.
2. There is a risk of core flush in 5% CO₂ regimes, particularly after cool growing seasons.
3. Ensure that O₂ level does not fall below 1.7% when controlling manually at 2% O₂, aim to keep a mean of 2%.
4. For operation at 1.2% O₂ use automatic equipment to control O₂ within the range 1.1-1.3%.
5. Operate store at 2% O₂ for at least one week before lowering to 1.2% O₂.
6. Restrict storage in 1.2% O₂ to Cox of good storage potential. In particular store only those fruit with calcium levels above 5 mg 100g⁻¹ and potassium levels below 150 mg 100g⁻¹. Avoid late picking.
7. After cool summers maintain minimum fruit temperature of 4°C (39°F) to reduce risk of low temperature breakdown.
8. Early picked fruit treated with SmartFresh™ at risk from russet browning. Treat fruit when starch coverage is below 70% and avoid temperature fluctuations after treatment.
9. Risk of core flush after January. Longer storage is possible in years of low core flush risk. To maximise storage period use 1.2% O₂ and maintain CO₂ levels below 1% for the entire storage period.

Discovery

Table 13 - Recommended storage conditions for Discovery

<table>
<thead>
<tr>
<th>Air storage</th>
<th>With SmartFresh™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
<td>Terminate (month)</td>
</tr>
<tr>
<td>1.5 - 2.0</td>
<td>10 days</td>
</tr>
</tbody>
</table>

Controlled atmosphere – No scrubber

With SmartFresh™
### Controlled atmosphere – Using a scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>%O₂</th>
<th>Terminate (month)</th>
<th>Notes</th>
<th>Terminate (month)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 - 2.0</td>
<td>&lt;1</td>
<td>2</td>
<td>45 days</td>
<td>1, 3, 4, 5</td>
<td>Few results</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
1. Cool quickly, preferably with forced-air pre-cooler.
2. Establish high CO₂ by adding dry ice to store.
3. Establish low O₂ by nitrogen injection.
4. Ensure that O₂ level does not fall below 1.7% when controlling manually at 2% O₂, aim to keep a mean of 2%.
5. The maximum post-storage life is only 4-5 days.

### Egremont Russet

**Table 14 - Recommended storage conditions for Egremont Russet**

#### Air storage

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>Terminate (month)</th>
<th>Terminate (month)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 - 3.5</td>
<td>December</td>
<td>December</td>
<td></td>
</tr>
</tbody>
</table>

#### Controlled atmosphere – No scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**With SmartFresh™**
Controlled atmosphere – Using a scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>%O₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>%O₂</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 - 3.5</td>
<td>5</td>
<td>3</td>
<td>Early March</td>
<td>1, 2, 4</td>
<td>5</td>
<td>1.2</td>
<td>April*</td>
<td>1, 2, 4, 5, 6</td>
<td>March</td>
</tr>
</tbody>
</table>

*The authors are grateful to Worldwide Fruit Ltd for generously agreeing to the release of results of trials with the 5% CO₂ + 1.2% O₂ regime conducted originally by Home Grown Fruits Ltd.

Notes:

1. Risk of shrivel; reduce by loosely covering the top layer of fruit in each bin with polythene.
2. Fruit may soften rapidly after storage and prompt marketing is advised. Use cool temperatures during holding and distribution of graded fruit.
3. Do not use on early-picked fruit for pre-Christmas sales.
4. Ensure that the recommended CO₂ level is not exceeded by more than 0.5%.
5. For operation at 1.2% O₂ use automatic equipment to control O₂ within the range 1.1-1.3%.
6. Where fruit in store is sufficiently firm raise the O₂ level to 2-3% a month before opening the store in order to improve flavour.

Empire

Table 15 - Recommended storage conditions for Empire

<table>
<thead>
<tr>
<th>Air storage</th>
<th>With SmartFresh™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
<td>Terminate (month)</td>
</tr>
<tr>
<td>3.5 - 4.0</td>
<td>Not set</td>
</tr>
</tbody>
</table>

Controlled atmosphere – Using a scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>%O₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Temp. °C</th>
<th>%CO₂</th>
<th>%O₂</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Limited storage research has been carried out on Empire in the UK. There are no recommendations for storage in elevated CO\textsubscript{2} (un-scrubbed) only.

Notes:
1. Ensure that O\textsubscript{2} level does not fall below 1.7% when controlling manually at 2% O\textsubscript{2}, aim to keep a mean of 2%.
2. In Canada (Ontario) Empire apples are stored at 1-2\textdegree C. However, where Smart\textregistered Fresh\textsuperscript{TM} is used storage temperature is raised to 2-2.2\textdegree C
3. Canadian Empire are stored in ‘standard’ CA(2% CO\textsubscript{2} + 2.5% O\textsubscript{2}) or ‘low oxygen’ CA(1.5% CO\textsubscript{2} + 1.5% O\textsubscript{2}). However, where Smart\textregistered Fresh\textsuperscript{TM} is used the CO\textsubscript{2} concentration in both types of CA would be reduced to <0.5% due to the increased susceptibility to CO\textsubscript{2} injury.
4. In New York State, USA and in New Zealand Empire apples are generally stored in 2% O\textsubscript{2}.

**Falstaff**

Table 16 - Recommended storage conditions for Falstaff

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>With Smart\textsuperscript{TM}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Terminate (month)</td>
</tr>
<tr>
<td>1.0 - 1.5</td>
<td>January</td>
</tr>
<tr>
<td></td>
<td>Few results</td>
</tr>
</tbody>
</table>

There is no research experience with CA storage in the UK.

**Gala and clones**

Table 17 - Recommended storage conditions for Gala and clones

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>With Smart\textsuperscript{TM}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Terminate (month)</td>
</tr>
<tr>
<td>0 - 0.5</td>
<td>Md December</td>
</tr>
<tr>
<td></td>
<td>December</td>
</tr>
</tbody>
</table>

**Controlled atmosphere – No scrubber**
<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>% CO₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Temp. °C</th>
<th>% CO₂</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.5</td>
<td>8</td>
<td>Early November</td>
<td>January</td>
<td>1.5 - 2.0</td>
<td>5</td>
<td>Early April</td>
<td>2, 3</td>
</tr>
</tbody>
</table>

**Controlled atmosphere – Using a scrubber**

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>% CO₂</th>
<th>% O₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.5</td>
<td>&lt;1</td>
<td>2</td>
<td>Early Jan</td>
<td>1</td>
<td>Few results</td>
<td>Md February</td>
</tr>
<tr>
<td>0 - 0.5</td>
<td>&lt;1</td>
<td>1</td>
<td>Mid Feb</td>
<td>2</td>
<td>Md February</td>
<td>April</td>
</tr>
<tr>
<td>1.5-2.0</td>
<td>5</td>
<td>1</td>
<td>Early April</td>
<td>2, 3</td>
<td>April</td>
<td>April</td>
</tr>
</tbody>
</table>

**Notes:**
1. Ensure that O₂ level does not fall below 1.7% when controlling manually at 2% O₂, aim to keep a mean of 2%.
2. For operation at 1% O₂ use automatic equipment to control O₂ within the range 0.9-1.1%.
3. Ensure that the recommended CO₂ level is not exceeded by more than 0.5%.

**Golden Delicious**

**Table 18 - Recommended storage conditions for Golden Delicious**

**Air storage**

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>Terminate (month)</th>
<th>Terminate (month)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 - 2.0</td>
<td>January</td>
<td>Few results</td>
<td></td>
</tr>
</tbody>
</table>

**Controlled atmosphere – No scrubber**

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>% CO₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
</table>
### Controlled atmosphere – Using a scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>% CO₂</th>
<th>% O₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 - 3.5</td>
<td>5</td>
<td>3</td>
<td>April</td>
<td>1, 3, 4</td>
<td>Few results</td>
<td></td>
</tr>
</tbody>
</table>

**There is no recent storage research to evaluate the response of Golden Delicious to low oxygen (1-1.5%) conditions.**

**Notes:**
1. Risk of scald - use appropriate post-harvest chemical treatment.
2. Risk of core flush and breakdown in some years at store temperatures below 3.5°C in 8% CO₂.
3. Risk of core flush and breakdown in some years at store temperatures below 1.5°C in air or 5% CO₂ + 3% O₂.
4. Ensure that the recommended CO₂ level is not exceeded by more than 0.5%.

### Idared

#### Table 19 - Recommended storage conditions for Idared

<table>
<thead>
<tr>
<th>Air storage</th>
<th>With SmartFresh™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
<td>Terminate (month)</td>
</tr>
<tr>
<td>3.5 - 4.0</td>
<td>Not set</td>
</tr>
</tbody>
</table>

#### Controlled atmosphere – No scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>% CO₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
</table>
### Controlled atmosphere – Using a scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>% CO₂</th>
<th>% O₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 - 4.0</td>
<td>5</td>
<td>3</td>
<td>May</td>
<td>1, 4</td>
<td>Few results</td>
<td></td>
</tr>
<tr>
<td>&lt;1</td>
<td>&lt;1</td>
<td>1-1.2</td>
<td>May</td>
<td>1, 2, 3</td>
<td>Few results</td>
<td></td>
</tr>
</tbody>
</table>

#### Notes:

1. Risk of core flush during distribution through the market.
2. Risk of Jonathan spot in 1-1.2% O₂ after hot summers.
3. Preferred CA condition is <1% CO₂ + 1% O₂.
4. Ensure that the recommended CO₂ level is not exceeded by more than 0.5%.

---

### Jazz (provisional recommendations)

Table 20 - Recommended storage conditions for Jazz (provisional)

<table>
<thead>
<tr>
<th>Air storage</th>
<th>With SmartFresh™</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temp. °C</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5 - 0.8</td>
</tr>
</tbody>
</table>

---

### Controlled atmosphere – Using a scrubber

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>% CO₂</th>
<th>% O₂</th>
<th>Terminate</th>
<th>Notes</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 - 0.8</td>
<td>&lt;1</td>
<td>3</td>
<td>N/A</td>
<td>1, 2</td>
<td>Few results</td>
<td></td>
</tr>
<tr>
<td>1 - 1.5</td>
<td>1.5 - 1.8</td>
<td>N/A</td>
<td>N/A</td>
<td>1, 3</td>
<td>Few results</td>
<td></td>
</tr>
</tbody>
</table>
There is no research experience with storage of Jazz in the UK. No recommendations for storage in elevated CO\textsubscript{2} (un-scrubbed) only.

Notes:
1. Exclusive to Worldwide Fruit Ltd.
2. Based on New Zealand experience.
3. Based on French experience.

### Jonagold and clones

Table 21 - Recommended storage conditions for Jonagold and clones

<table>
<thead>
<tr>
<th>Air storage</th>
<th>With SmartFresh\textsuperscript{TM}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
<td>Terminate (month)</td>
</tr>
<tr>
<td>0 - 0.5</td>
<td>January</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Controlled atmosphere – No scrubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
</tr>
<tr>
<td>1.5 - 2.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Controlled atmosphere – Using a scrubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
</tr>
<tr>
<td>1.5 - 2.0</td>
</tr>
</tbody>
</table>
1. Ensure that the recommended CO₂ level is not exceeded by more than 0.5%.
2. For operation at 1.2% O₂ use automatic equipment to control O₂ within the range 1.1-1.3%.

**Kanzi**

There has been no research done in the UK on the storage of Kanzi apples. Storage conditions used in Belgium were 1°C, 3% O₂ and 0.7% CO₂. However, there was concern that the storage temperature may be too low.

The Kanzi ‘Club’ should be contacted regarding commercial experience of storing this cultivar in the UK.

**Meridian (interim recommendations)**

Table 22 - Recommended storage conditions for Meridian (interim recommendations)

<table>
<thead>
<tr>
<th>Air storage</th>
<th>With SmartFresh™</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temp. °C</strong></td>
<td><strong>Terminate</strong> (month)</td>
</tr>
<tr>
<td>3.0</td>
<td>October</td>
</tr>
</tbody>
</table>

**Controlled atmosphere – Using a scrubber**

<table>
<thead>
<tr>
<th>Controlled atmosphere – Using a scrubber</th>
<th>With SmartFresh™</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temp. °C</strong></td>
<td><strong>% CO₂</strong></td>
</tr>
<tr>
<td>3.5 - 4.0</td>
<td>&lt;1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

There are no recommendations for storage in elevated CO₂ only (un-scrubbed CA).

**Notes:**

1. For operation at 1.2% O₂ use automatic equipment to control O₂ within the range 1.1-1.3%.
2. For operation at 1% O₂ use automatic equipment to control O₂ within the range 0.9-1.1%.
3. Ensure that the recommended CO₂ level is not exceeded by more than 0.5%.
4. Avoid late harvesting. Pick when fruit firmness is between 7-7.5 kg and monitor the condition of fruit in store at regular intervals.

**Red Pippin**

Table 23 - Recommended storage conditions for Red Pippin

| Air storage | |
|-------------| |
There are no recommendations for storage in elevated CO\textsubscript{2} only (un-scrubbed CA).

Notes:
1. Ensure that the recommended CO\textsubscript{2} level is not exceeded by more than 0.5%.
2. Ensure that O\textsubscript{2} level does not fall below 1.7% when controlling manually at 2% O\textsubscript{2}, aim to keep a mean of 2%.
3. To achieve the green background ex-store required for Red Pippin avoid late picking.
4. For operation at 1.2% O\textsubscript{2} use automatic equipment to control O\textsubscript{2} within the range 1.1-1.3%.
5. There is a risk of scald during marketing.

**Rubens (provisional recommendation)**

Table 24 - Recommended storage conditions for Rubens (provisional)
There is no research experience with storage of Rubens in the UK. Recommendation based on Italian experience. No recommendations for storage in elevated CO$_2$ (un-scrubbed) only.

**Spartan**

**Table 25 - Recommended storage conditions for Spartan**

<table>
<thead>
<tr>
<th>Air storage</th>
<th>With SmartFresh™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
<td>Terminate (month)</td>
</tr>
<tr>
<td>0 - 0.5</td>
<td>January</td>
</tr>
</tbody>
</table>

**Controlled atmosphere – Using a scrubber**

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>%CO$_2$</th>
<th>%O$_2$</th>
<th>Terminate</th>
<th>Notes</th>
<th>Terminate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 - 2.0</td>
<td>&lt;1</td>
<td>2</td>
<td>March</td>
<td>1, 3</td>
<td>Few results</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2</td>
<td>May</td>
<td>1, 2, 3</td>
<td>Few results</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

1. Ensure that O$_2$ level does not fall below 1.7% when controlling manually at 2% O$_2$, aim to keep a mean of 2%.
2. Ensure that the recommended CO$_2$ level is not exceeded by more than 0.5%.
3. Risk of breakdown if calcium concentrations in the fruit at harvest are less than 4 mg 100g$^{-1}$; apply calcium sprays and / or treat post-harvest with calcium chloride.

**Worcester Pearmain**
### Table 26 - Recommended storage conditions for Worcester Pearmain

<table>
<thead>
<tr>
<th>Air storage</th>
<th>With SmartFresh™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
<td>Terminate (month)</td>
</tr>
<tr>
<td>0 - 1.0</td>
<td>December</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Controlled atmosphere – No scrubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
</tr>
<tr>
<td>0.5 - 1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Controlled atmosphere – Using a scrubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. °C</td>
</tr>
<tr>
<td>0.5 - 1.0</td>
</tr>
</tbody>
</table>

**Notes:**
1. Risk of shrivel. Reduce this by loosely covering the top layer of fruit in each bin with polythene sheet.
2. Ensure that the recommended CO₂ level is not exceeded by more than 0.5%.

### Club cultivars

There are a number of cultivars being introduced into the UK that are subject to agreements between the growers and the ‘club’ operators.
- It is anticipated that storage advice for cultivars such as Cameo, Jazz, Konz and Rubens will be provided from within the respective ‘clubs’.
- No research has been carried out on these cultivars at EMR but some results are available from overseas and these form the basis for the recommendations provided in the tables.
- Since storage recommendations will be developed through trials done in commercial stores growers need to update themselves regularly with the latest information.
Experience abroad

Comprehensive summaries of the conditions recommended for the storage of commercially important cultivars of apples throughout the world were provided by Meheriuk (1993) and more recently by Kupferman (1997). It is clear from these summaries that the recommended storage conditions for any particular cultivar varies considerably between different growing regions.

- Climatic conditions have a major influence on the response of apples to conditions imposed during storage. Therefore it is not possible to establish universal standard conditions for any particular cultivar.
- Similarly morphological and physiological differences among cultivars affect their response to applied CA conditions which necessitates factorial experiments (carbon dioxide x oxygen x temperature) over several seasons to establish safe effective regimes.
- It is important that growers do not adopt storage regimes advocated in other growing areas as serious damage could be induced in the fruit.
- It is helpful to researchers to be aware of the storage regimes used around the world as these indicate the comparative sensitivities of cultivars to low temperatures, lowered oxygen and elevated carbon dioxide.
- This information is helpful in the planning of storage experiments for cultivars grown in the UK.

Future developments

State-of-the-art CA storage facilities that maintain the most appropriate storage conditions exist in most apple-producing countries. Johnson (1999a) recently reviewed the development of CA storage for apples in the UK. He felt that the recommended temperatures and atmospheres of carbon dioxide and oxygen were approaching the limits tolerated by stored apples and that it was unlikely that there would be benefit from further adjustment of conditions without risking damage to the fruit. However, it was recognised that future recommendations would be sensitive to particular demands by consumers and retailers.

In the current situation of a world over-supply of apples there is a greater emphasis on eating quality, particular texture, than on the duration of storage. Future recommendations may need to promote other quality attributes, for example flavour or health properties such as antioxidant content. Recognising the desire to reduce chemical inputs such as post-harvest treatment with fungicides or diphenylamine (DPA), it may be necessary to adopt the most appropriate conditions to control fungal rotting and superficial scald respectively.

There may be further development of ‘adaptive’ or ‘dynamic’ CA systems where the lowest possible oxygen concentration is maintained using a feedback system which ventilates the store with air in response to the detection of fermentation products (ethanol) in the atmosphere or changes in the calculated respiration rate or other physiological indicators such as chlorophyll fluorescence.

Recent work in Holland has demonstrated improved quality in Elstar apples using a hand-operated dynamic control system based on ethanol detection (Schouten et al., 1997). The oxygen concentrations in some commercial apple stores in the South Tyrol region of Italy are being controlled using a chlorophyll fluorescence sensor to detect low-oxygen stress (Zanella et al., 2008). Similar systems based on respiratory responses improved the firmness of Cox apples compared with conventionally controlled ultra-low oxygen (ULO) conditions (Jameson, 1997).

Although dynamic or adaptive control offers the prospect of tailoring the store atmosphere to suit particular consignments of fruit it cannot be assumed that optimum quality will be achieved in all cultivars using these methods.

- Cox apples are susceptible to late storage corking and McIntosh apples may develop corky flesh browning when kept under ULO conditions for prolonged periods.
- Dynamic or adaptive CA is an exciting prospect for the control of scald on Bramley apples without the use of DPA. Bramley can tolerate oxygen levels as low as 0.4%, but not for the entire storage period. With dynamic or adaptive control, oxygen concentration could be maintained below the current recommended minimum (1.0% O2) and varied according to the oxygen demand of the fruit. Significant extension of the scald-free period for fruit not treated with DPA is anticipated using this approach.

Further research requirements

1. There will be a continued need to provide storage recommendations for existing and new cultivars of apple that enable growers to achieve the quality and period of supply demanded by consumers. Work is currently underway to refine the storage recommendations for Braeburn apples with the objective of overcoming problems with core flush that currently prevents storage until late April. There is a need to fully evaluate the storage potential of ‘club’ varieties being introduced into the UK. Robust recommendations are likely to be generated more effectively through controlled factorial experiments as opposed to ‘ad hoc’ treatments applied using of commercial stores. Existing recommendations may need to be modified in line with expected changes in quality requirements that currently are directed more towards health benefits in addition to sensory fulfilment.

2. Further work is required to test the robustness of dynamic or adaptive control techniques in UK apples from a range of orchards produced in different years. Work should focus on Bramley since there is major opportunity to control scald without the use of DPA or SmartFresh™.

Post storage grading of fruits

Once a store is opened fruit should be assessed against customer specification requirements and graded to deliver optimum return to the grower.

Planning

- Before a store is opened, all available information should be assessed.
- Pre-storage assessment and store monitoring data will be vital in determining the potential marketing outlet.
- Only fruit with the potential for a good grade-out will be worth packing for a multiple retailer (supermarket) outlet.
- Poor raw material may end up producing a negative return if allowed to enter the higher cost operation required for multiple customers.

Customer specification

Depending on which outlet the fruit is intended for i.e. multiple, wholesale, or processing, assessment will need to reflect customer specification.

- All standards will involve visual, textural, internal and organoleptic characteristics.
- Multiple standards will be the highest for all quality characteristics, but processing will still require fruit of good shape and freedom from internal problems including under skin bruising.
- The minimum standard for any product sold into the wholesale or multiple sector must meet EC (Defra) standards.
- Visual standards cover shape, colour, and the amount of bruising and blemish, freedom from pests, diseases and foreign matter.
- Textural standards recognise that good textured fruit are generally firm. Firmness measurements are a standard requirement for all multiple customers, and all now use an electronic penetrometer also known as Fruit Texture Analyser (FTA).
- Good textural quality will also be associated with fruit tissue in which cells break under pressure from the teeth thus releasing juice and flavour. In contrast in fruits that are described as ‘mealy’ or ‘floury’ the cells will separate under pressure from teeth and will fail to liberate juice. Currently there is no instrument that is equivalent to the penetrometer that can be used to indicate an acceptable texture in soft fruit.

- Internal standards require freedom from disorders such as bitter pit, low temperature and senescent breakdown, carbon-dioxide injury, etc.

- Organoleptic standards are concerned with levels of sugar (°Brix) and acidity and freedom from any taints or off-flavours. Overall acceptance by taste panels will be part of some customer specifications.

- All consignments of fruit supplied to multiple retailers must be traceable. They should be from an approved source and an Assured Produce number is required where the Red Tractor logo is used.

- Also individual multiple retailers have different audit requirements on top of Assured Produce that need to be achieved. For example, ‘Tesco has its Nature’s Choice standard, M&S has Field to Fork and Waitrose has adopted LEAF.

Pre-grading assessment
- As soon as the store is opened an assessment of the fruit from each orchard should be undertaken. In practical terms this may have to be an on-going process due to access to fruit from particular orchards.

- Ideally 100 apples taken from a minimum of 20 bins from each orchard should be assessed and sized in 5mm bands.

- Assessment should be made against the intended customer specification.

- Assessments for fruit in each size band will take into account all the visual, textual, internal and organoleptic criteria indicated above.

- This then enables fruit to be allocated to different customers much easier before it is graded.

- Once an assessment report has been made, and customer target confirmed, levels of staff on the inspection tables can be decided and any instructions given regarding particular defects.

- On-going assessment of raw material from each orchard should continue to take place on a daily basis to confirm the status of the fruit prior to grading. The results should be recorded and entered into a raw material assessment report.

Temperature of fruit during packing
- Ideally packhouses should be air-conditioned with a working temperature around 10°C.

- The temperature of fruit at packing may influence the level of grader damage as fruit passes along the line.

- Some varieties, such as Discovery, are more susceptible than others to grader damage.

Time between harvest and packing
- An interval between picking and packing will be required to reduce grader damage and will be influenced by variety and weather at picking time.

- Heavy rain prior to harvest will result in turgid fruit, which will bruise easily if graded too quickly.

- Depending on the grading equipment, it may require up to a week for fruit to reach a condition allowing satisfactory handling, without drastically reducing grade-out.

- If uncertainty about a batch exists, it would be good practice to either grade a small batch or, if possible, simulate fruit grader movement to evaluate the probability of damage occurring.

- The later varieties like Braeburn require a period of storage before fruit is eating at its best, therefore regular sampling is required to decide when fruit is ready for grading.

Equipment
- Selection of equipment equal to the task should be part of any assessment before committing apples to a packing line.

- The scale of operation will influence the equipment decision.

- Large packing operations depend on large volume throughput for cost-efficient operation.

- Small/medium sites will generally grade and pack as part of one operation.

- Large operations will generally carry out the grading and packing in two parts.

- Raw material should be off-loaded by water flotation into water flumes, passing onto the grading line where fruit size, colour and defects are sorted either with human selection or by high specification camera.

- Fruit is then returned to designated water flumes before, collection and return to bins.

- Bins are then returned to cold store, before returning to the packing line.

- The intended customer outlet i.e. multiple, wholesaler or processor may also influence the decision on grading.

- Lower value outlets may not justify the use of expensive high technology operations.

Dry tip or water flotation
- Dry tip operations will only be justified in a small operation. Where dry tipping is used the tipper should always be of the type unloading from the top of the inverted bin, reducing movement of fruits within the bin.

- Other types of tipper where fruit is down loaded from the bottom cause fruit to be bruised, blemished or punctured by stalks. In addition, any rots within the bin will break up causing rot residue to infiltrate the packed product.

- Dry tipping should make use of a water cleansing system (spray bars fitted in line using potable water) to remove where possible any undesirable foreign matter (rot residue, dust etc.).

- Ideally water flotation systems will start with automated bin down loading, allowing fork-lift truck loading of the equipment and automatic selection (usually from stacks of three, on a roller feed entry system) of fresh bins into the water flotation system, reducing unnecessary labour input. Empty bins will be collected and removed in the same manner.

- Once down-loaded the fruit will travel in water flumes to the grader.

Optical sizing and colour selection
- Sizing has moved on from historic rising bar systems and weight graders that can be difficult to calibrate accurately when fruit density and shape varies. Both historic systems fail to deliver size grading which is accurate enough for today’s customer requirements.

- Even sizing within a container is vital.

- Optical sizing by camera is the current best practice.

- In many pack-houses colour selection is now carried out by camera. The latest technology will allow colour streaming which enables a more uniform colour.
Motivation

Staff training

Calibration of equipment

Relationship between size and weight

Calibration of equipment

Accurate grading/assessment

Staff training

Motivation

Quality selection by camera technology

Non-destructive (infra-red) texture selection

Gentle and efficient movement of fruit through the grading and packing system

Delivery of accurate size and consistent pack weights will depend on optimising performance where a weight grader is used.

Optical cameras for sizing will improve sizing accuracy, but fruit density will still influence pack weights particularly where packs are by ‘count’ but a minimum pack weight is still required.

Delivering accurate size and consistent pack weights will depend on regular calibration of any grader but particularly where a weight grader is used.

Fruit should be monitored regularly to assess accuracy, and the grader re-calibrated where necessary.

Delivering accurate grading performance is vital for any pack-house intending to stay competitive.

Under-grading will put customer service levels at risk resulting in possible de-listing.

Over-grading will result in reduced financial returns to the grower and loss of potential business for the packer.

It is therefore vital that quality controllers assess the performance of the grading line on a regular basis. This should be done at each step of the production line.

It is vital that all product is assessed i.e. Class 1, Class 2 and any out-grade fruit. This is particularly important, as it is very easy to over-grade when attempting to satisfy a demanding retail customer.

All packhouses must recognise the customer base is grower and retailer together if they are to succeed.

Best practice should deliver accurate grading acceptable to the grower and retail customer.

Staff training is a critical part of packhouse performance.

Training should always be targeted at the level required. For example, all staff must have induction training to take account of site health and safety issues.

General training should be given to ensure each worker has the level of skill required for his or her tasks.

Grading staff need to be fully conversant with customer specification requirements. This may be achieved by training in the aspects of the specification which are key to the task involved.

All packhouse staff should be aware of grading standards and should be prepared to remove defective fruit at any stage of grading rather than rely on others to do so.

Supervisors will need to be conversant with all aspects under their control.

Motivation

Motivation is an important factor.

Personnel will respond to various motivation factors.
Post-harvest chemical treatment and cooling of apples

This section of the Guide has changed significantly since the first edition was produced in 2001. At that time a number of fungicides were registered for use on apples as a post-harvest dip or drench. These included formulations of carbendazim and thiophanate-methyl and a mixture of carbendazim and metalaxyl.

There are currently no fungicides registered in the UK for post-harvest application to apples (although, for pears, prodione still has off-label approval for dipping or drenching).

Several factors have contributed to this situation. The main factor has been public concern over the use of pesticides and chemical residues in food at the time of consumption. Clearly the general public does not appreciate the concept of MRLs and wants no detectable pesticide on the food when it is eaten.

A second important factor has been the realisation that the application of fungicides to apples after harvest has only a limited effect in reducing fungal spoilage. More effective control of rots can be achieved by chemical intervention in the orchard to prevent initial infections and much can be done with a non-chemical approach. Other factors of concern about post-harvest fungicide use include the problems associated with disposal of drench solutions.

Information on the post-harvest application of fungicides is no longer relevant since there are no products approved for this use in the UK. However, those interested in aspects of fungicide use should consult the 2001 edition of the Guide (out of print).

The remainder of this section is relevant to the post-harvest application of diphenylamine (DPA) for scald control and calcium for control of bitter pit and other calcium deficiency disorders. Although the development of SmartFresh® has reduced the reliance on DPA for scald control, a significant proportion of Bramley growers have a continuing need to apply DPA.

Although SmartFresh® application could be included in this section dealing with post-harvest chemicals, there are a number of reasons why it is dealt with in more detail separately.

Although SmartFresh® is a chemical treatment, it is not applied as a liquid drench or dip and therefore does not present any problems with disposal. The active ingredient of SmartFresh® is 1-methylcyclopropene (1-MCP) which is released as a gas when water is added to the formulated product. The concentration of 1-MCP in the atmosphere of the store during treatment (usually 24 hours) is low (usually 625 parts per billion) and leaves no detectable residue in the fruit.

At the present time the storage environment is modified to retard senescence changes and optimise fruit quality. The priority in the future may be to control wastage due to rotting. However, there needs to be an increased understanding of the effects of the components of the storage atmosphere on disease development both in vivo and in vitro before changes can be made in storage recommendations.

Post-harvest application of chemical antioxidants and calcium products

Only treat fruit post-harvest with a chemical where a significant risk of fruit losses has been identified. Place fruit in a store where the fabric, including the floor has been cooled down to below the final holding temperature. The following advice should be adhered to in order to restrict the use of chemicals where possible and to ensure the most efficacious type of consignments of fruit where this is deemed to be necessary.

- Avoid the unnecessary application of post-harvest chemical treatments by estimating the risk of disorders developing in the fruit during storage.
- Growers should contact their marketing organisations regarding their attitude to the proposed application of post-harvest chemical treatments. It is important that the growers are ‘in-tune’ with the requirements of their immediate customers as well as being generally aware of consumers’ attitudes and concerns.

Superficial scald

- To prevent superficial scald development in Bramley apples, apply full strength (2000 ppm) diphenylamine (DPA) where fruit is to be stored in ventilated CA conditions (80% CO2) beyond November.
- Fruit stored in scrubbed, low-oxygen stores at 5% CO2 + 1% O2 (5/1) need not be DPA treated where fruit is to be marketed by the end of March.
- Fruit stored in 5/1 for longer periods should be treated with half strength DPA solution.
- For untreated fruit stored in 5/1 it is important to establish CA conditions slowly to avoid CO2 injury.
- SmartFresh® can be used as an alternative to DPA for scald control in Bramley apples.
- Ethylene scrubbing can be also considered as an alternative to DPA for scald control in Bramley apples.

Calcium treatment for bitter pit

- Assess the requirement for post-harvest calcium application by taking samples of fruit for mineral analysis 2 weeks prior to harvest. Where calcium levels are lower than those recommended, calcium treatment is advisable.
- Do not exceed the suggested dose for any calcium product as damage to the skin may result. Only treat cultivars that are listed on the product labels.
- Post-harvest calcium treatments should be applied only to cultivars that are susceptible to calcium deficiency disorders, for which pre-harvest fruit analysis will indicate the need for supplementing calcium concentration.

Staff training and certification for post harvest treatment

- Growers should be aware of the legal requirements regarding operatives involved in the drenching or dipping of fruit with chemicals.
- All contractors or staff born after 31 December 1994 who apply pesticides must have attended and passed a National Proficiency Test Council (NPTC)-recognised course in The Safe Use and Handling of Pesticides (PA1), together with courses for the relevant piece of machinery (PA10 for drenchers).
- Those who are operating under the so-called ‘grandfather rights’ will need to produce a certificate of attendance at a recognised i.e. NPTC training course both in the Safe Use of Pesticides and the Post-Harvest Application of Pesticides.
Equipment calibration for post harvest treatment

The following procedures should be adopted for calibration:

- Measure volume of tank.
  - For square tanks calculate volume = height x length x width.
  - For round tanks calculate volume = radius x radius x height x 3.142.
  - For measurements in metres multiply volume (cubic metres) by 1000 to provide volume in litres.
  - For measurements in feet multiply volume (cubic feet) by 6.24 to provide volume in gallons.
- Measuring jugs and scales should be specific for the job and not used for any other purpose.

Good practice preparing for post harvest treatment

The following procedures should be adopted for operation:

- Mark the tank to show the operating level (full).
- Add clean water until the tank is approximately three-quarters full.
- Use a clear area to weigh or dispense chemicals.
- List chemicals and quantities used in each tank mix.
- Dilute the concentrate in the ratio of 1 part chemical to 9 parts water. Always cream wettable powders in water before adding to the tank.
- Add to the tank and fill to the mark. Mix for at least 10 minutes.
- Label tank clearly with contents.
- In order to prolong the life of the solution any soil should be removed from the outside of bins to prevent soiling of the yard and of the drenching/dipping solution.
- Separate the bin reception area from the standing area for treated bins.

Good practice during post harvest treatment

- Treat fruit for 60 seconds maximum.
- Fruit should not be treated above 21°C or below 10°C (optimum 16°C).
- Top-up using solution diluted to the correct concentration.
- Change solution every 2 or 3 days or when excessively dirty. DPA manufacturers suggest refilling with fresh solution after every 100 bins. This may be fewer than are treated in practice, particularly where dip tanks are used.

Good practice following post harvest treatment

- Dispose of the used (dilute) solution on an area of land authorised for the purpose by the Environment Agency, via a licensed waste disposal company or by the use of equipment designed specifically to treat waste pesticides.
- After chemical treatment allow the fruit to drain before stacking into a store that has been cooled thoroughly prior to loading.
- Stores with insulated floors should be pre-cooled for 5 days and those with un-insulated floors for 10 days.
- Ensure that the refrigeration plant is switched off during loading. Use other available stores for pre-cooling fruit prior to loading.
- Ensure that fruit reaches the final holding temperature within 5 days of the start of loading.

Concerns of the consumer

Until recently on many farms it was routine practice to treat apples prior to storage with specific fungicides in order to control infections of fruit by fungi such as Gloeosporium, Botrytis, Monilinia and Phytophthora (see Part 2 of the Guide for illustrations and descriptions of the various types of rot).

At the present time this method of applying fungicides is no longer possible due to the lack of products registered for use in this way. However, chemical antioxidants, such as diphenylamine (DPA), continue to be used routinely for the control of superficial scald on Bramley’s Seedling and products containing calcium are used frequently to increase the calcium concentration in the fruit and thereby reduce the development of calcium-deficiency disorders such as bitter pit.

Previous recommendations for the post-harvest chemical treatment of apples were concerned primarily with achieving control of particular disorders and enabling growers to save chemical and time by avoiding unnecessary emptying and refilling of dippers or drenching tanks.

Today the major consideration in the minds of growers when deciding their strategy for post-harvest chemical treatments should be the public perception of those treatments.

Apples have always had a healthy image and this provides a very strong marketing tool for fresh apples and apple products. In their book, “Super Foods”, Michael Van Straten and Barbara Griggs list apples as one of “The Four-Star Super Foods”. They claim that apples are a bonus for the heart: the pectin and vitamin C in apples helps to keep cholesterol levels stable.

- Pectin has been shown to bind to heavy metals such as lead or mercury and carry them safely out of the body.
- Malic and tartaric acids in apples help neutralize the acid by-products of indigestion and helps the body cope with excess protein or rich fatty foods.
- The authors conclude “because of these qualities, apples are great detoxifiers, and those suffering from arthritis, rheumatism or gout should eat raw apples regularly”.

In recent years the consumer has become more concerned about the use of pesticides and residues on the food they eat. Nearly every week the words ‘apples and pesticides’ appear in the same article or broadcast.

- The Government's residue testing of food programme has highlighted and quantified this concern.
- The results are published annually together with the source of the sample, the so-called 'name and shame' policy.
- Where any pesticide is found above the level of detection the results are published.
- Maximum residue levels (MRLs) have been set as a measure of concentrations that can be expected with normal use of the pesticide and are safe for human health.
- Post-harvest treatments by their very mode of action are always going to leave a residue on the apple.
- The cold, dark environment of fruit stores slows chemical degradation. Thus, any residue will remain on the apple and is not easily washed off.

Although the economic benefit of using post-harvest chemicals is clear, in today's consumer-driven climate, their use should be considered very carefully.

Assessing the risk of superficial scald developing

In order to avoid the unnecessary application of post-harvest chemical treatments to apples the risk of disorders should be established for each consignment of apples. The risk of superficial scald is influenced by climatic conditions during fruit development; hot dry conditions are generally conducive to scald development during storage.

Although formulae to predict scald in Bramley apples have been developed, these are of limited practical use at the present time. These relate to fruit stored in ventilated CA conditions of 8-10% CO₂ (11-13% O₂) where the risk of scald is high compared with scrubbed, low oxygen storage.

Further work is required to increase robustness of scald prediction models for storage in ventilated CA storage. These need to include the marked effects of harvest date on scald potential (early harvested fruit are more likely to develop scald) and the effects of store air circulation, position of fruit within bins and position of bins within the store.

- Until the influence of all these factors on scald development have been resolved and included in a prediction model the advice to growers is to apply DPA to all fruit for storage regardless of risk or to use alternatives such as SmartFresh™ or ethylene scrubbing.
- Application of DPA for the control of superficial scald on Bramley's Seedling should be regarded as routine for all fruit stored beyond November in conventional CA conditions of 8-10% CO₂ (11-13% O₂) at 4-4.5°C.
- Where growers have facilities to maintain scrubbed, low-oxygen conditions of 5% CO₂ + 1% O₂ (5/1) post-harvest treatment with DPA is unnecessary for fruit stored for 6 months or less.
- However, where DPA is omitted it is important to delay the establishment of CA conditions in order to avoid possible CO₂ injury. Experience has shown that half-rate DPA (1000 ppm) is effective in controlling scald in 5/1 storage beyond March.

Chemicals treatments

Clearly there will be continued pressure from consumers to reduce or eliminate the use of post-harvest chemical treatments for apples and other fresh produce. The number of products with label recommendations for use as post-harvest treatments has declined over the last few years. A list of products with current approval is given in Table 8.

<table>
<thead>
<tr>
<th>Product</th>
<th>Rate (metric)</th>
<th>Rate (imperial)</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1000 litres⁻¹</td>
<td>100 gallons⁻¹</td>
<td></td>
</tr>
<tr>
<td>DPA 15%</td>
<td>13.3 litres</td>
<td>10.6 pints</td>
<td>Bramley</td>
</tr>
<tr>
<td>DPA 31%</td>
<td>6.4 litres</td>
<td>5.1 pints</td>
<td>Bramley</td>
</tr>
<tr>
<td>Ethoxyquin</td>
<td>3.7 litres</td>
<td>3 pints</td>
<td>Bramley</td>
</tr>
<tr>
<td>Stopit</td>
<td>13.5 litres</td>
<td>10.8 pints</td>
<td>Cox</td>
</tr>
<tr>
<td>Calcium Chloride Flake</td>
<td>13.5 kg</td>
<td>13.5 pounds</td>
<td>Cox</td>
</tr>
<tr>
<td>Calcium Chloride Liquor</td>
<td>13.3 litres</td>
<td>10.6 pints</td>
<td>Cox</td>
</tr>
<tr>
<td>Calcium Metalosate</td>
<td>6.3 litres</td>
<td>5.0 pints</td>
<td>Apples</td>
</tr>
</tbody>
</table>
Planning

- Before handling or applying a pesticide always read the product label and follow any other guide-lines for use supplied by manufacturers.
- It is essential to follow the instructions on the approved label before handling, storing or using any crop-protection product.

Calcium treatments

Most experience at East Malling has been obtained with Cox's Orange Pippin apples. These should normally be treated with 9 kg 1000 litres\(^{-1}\) of flaked grade material although the rate may be increased to 13.5 kg 1000 litres\(^{-1}\) where the risk of bitter pit is high (Table 8).

- These rates are believed to be generally safe although in some seasons fruit from certain orchards in East Anglia have been slightly damaged. Further studies related susceptibility to injury to differences in the structure of the fruit cuticle.
- It is important to avoid over-dosing Cox apples with calcium chloride and to regard dipping or drenching in calcium as a last resort for improving their calcium status. The emphasis should be on the use of orchard sprays for supplementing calcium nutrition.
- Cultivars of apple that have been treated safely with 9 kg 1000 litres\(^{-1}\) of calcium chloride include Spartan, Laxton's Superb and Golden Delicious.
- Bramley's Seedling and Egremont Russett should not be treated with calcium chloride since severe lenticel injury may result. Calcium nitrate is not a permitted post-harvest additive and it is, in any case, more damaging than the chloride.
- It is preferable that growers use proprietary formulations of calcium and follow the instructions provided on the label.

Disposal of drench solutions

The Groundwater Regulations complete the implementation of the Groundwater Directive (Protection of Groundwater against pollution caused by certain dangerous substances - 80/68/EEC). Implementation of the Regulations helps prevent pollution of groundwater by controlling discharges or disposals of certain dangerous substances, including pesticides, where they are not already covered by existing legislation.

A drenching unit contains approximately 1000 litres and will treat on average 300 bins of fruit. Each bin will take out about two litres of solution, leaving about 400 litres to dispose of for each change. Disposal should be by one of the following methods:

- Place redundant solution in a suitable container pending collection by a registered waste disposal company for transport to a licensed waste disposal facility.
- Use suitable equipment designed to treat liquid waste containing pesticides, such as a Sentinel.
- Dispense on an area of land that has been authorised by the Environment Agency for the purpose. Authorisations must be subject to ‘prior investigation’.

Rapid cooling of fruit

Apples need to be cooled as quickly as possible in order to provide the longest duration of storage and to provide the highest quality. This applies to fruit treated with chemicals post-harvest and to those left untreated. In this regard there are obvious benefits in not treating with chemicals as this only serves to delay prompt loading of stores.

To ensure that stores are loaded and the operating temperatures are achieved within 5 days of the start of loading the following points should be observed:

- The desired cooling rates will not be achieved unless the store is well insulated and there is sufficient refrigeration capacity to bring to bear during the pull-down period.
- Walls and ceilings should have 125 to 150 mm of expanded polystyrene or 100 to 150 mm of polyurethane.
- The construction of the floor should include 50 mm of heavy-duty polystyrene.
- The store air must be circulated quickly and distributed evenly through the whole of the stored product.
- The fans should be capable of producing forty changes of the store volume every hour.
- Allow at least a 50 mm gap between each tier of bins.
- Bins of fruit should be loaded into a store that has been cooled thoroughly for at least 2 weeks before loading.
- This ensures that the refrigeration plant is extracting primarily the field-heat of the apples and does not have to cope with undue heat ingress through the structure and to some extent the cold structure provides a small ‘ice-bank’ effect.
- It is important that during loading the refrigeration plant is switched off.
- The plant should be switched on when the door is not likely to be opened for some time.

Discharging of treated fruit bins pre-storage

- Apples that have been treated with a chemical or mixture of chemicals after harvest need to be placed on a hard standing for a period to allow the bins to drain prior to loading into store.
- This will minimise the amount of liquid accumulating on the store floor during loading and will reduce the hazard that slippery floors present to fork-lift operators.
- Additionally, drainage of excess liquid will minimise any potential injury from solutions containing DPA or calcium. The excess liquid should be collected and disposed of safely and legally.

Post-storage packing and distribution of fruit

Once graded, place fruit in a suitable container to avoid damage. All product should be “cool chained” up to and including the point of sale.

Planning

- Identify the intended customer.
- Plan packing against a known customer programme.
Ensure all personnel involved in the packing operation are fully conversant with the customer specification requirements, including all aspects of packaging.

Most multiple customers require dedicated crates, customised packaging and labelling.

Ensure sufficient stock of correct packaging is available to meet the programme.

Ensure all operatives have had induction training on site health and safety issues.

Ensure all on-line operatives have been trained for their specific tasks.

Ensure all equipment is in good working order, fit for purpose and calibrated where applicable.

Calibration records should be kept, with clear reference to identified equipment. This is particularly relevant to scales for weighing product on-line and for QC equipment.

It is a legal requirement that all product sold by minimum weight must be weighed on scales that have been DITI stamped i.e. approved by the Department of Trade and Industry, now Department for Business, Enterprise and Regulatory Reform (BERR). Any calibration by a certified engineer must have been carried out with weights traceable to national standards and identified as such on any calibration certificate.

A certified engineer should calibrate equipment at least once a year and more frequently on a busy site.

Calibration checks on scales must take place at least once a day before starting a production run and ideally at the end of the batch. Calibration weights should take account of the intended range in weights i.e. check using weights that represent the bottom and top end of the range.

Penetrometers, refractometers, thermometers, QC sizing rings and all scales must be calibrated regularly.

Identify labelling requirements and ensure equipment and associated software will produce labels compliant with customer specification.

Identify and install QC procedures required to meet customer requirements.

Customer programme

- Fruit should always be sold as part of an agreed customer programme, if optimum returns are to be realised.
- Programmes will allow controlled marketing. This will in turn allow packers to pack and distribute fruit in the optimum condition, with sufficient stock to be flexible on a day to day basis, but without unnecessary build-up and deterioration of stock.
- In practice the packhouse will receive a weekly programme, with order confirmation on a daily basis received from the sales office.
- The packer should ideally pack sufficient stock for the orders anticipated for the next day. On this basis fruit would not have been packed more than 36 hours before despatch. There will be exceptions to this rule, for example the build-up prior to Christmas. However, this must be an exception rather than the rule.
- Before fruit is accepted onto the line, it should be assessed as suitable for the intended customer. This should be done by reference to QC reports carried out at harvest and handling section. Additionally, as a minimum, pack-house supervisors should have a certificate for Basic Hygiene Training. Weights traceable to national standards and identified as such on any calibration certificate.

Packaging materials

- Packaging materials should be utilised for the customer, destination, and mode of transport.
- Best practice for multiple outlets will utilise plastic RDTs (retail display trays) as the outer packaging unit. RDTs also come in cardboard as the second favoured option.
- Wholesale markets often prefer a 30 lb or 40 lb sealed box, rather than RDTs.
- RDTs can be placed directly onto the retail shelf thus avoiding any unnecessary decanting of fruit. Decanting will inevitably increase the risk of in-store damage to the product and cost to the producer.
- Plastic crates offer the best protection for fruit in transit and are more cost efficient than cardboard equivalents. The turnaround cost comparison generally shows that plastic is half the cost of cardboard. In addition, regulations for the disposal of waste materials increase the hidden costs for cardboard.
- Internal packaging i.e. fibre-moulded trays offer the best protection for loose product and allow maximum presentation of loose product at the retail level.
- If product is well presented, it will reduce the level of consumer selection and handling in the store that so often spoils otherwise acceptable fruit. This spoiling of product and eye appeal detracts from sales.
- Pre-packed fruit in the form of polybags or over wraps offers two distinct advantages. Polybag fruit allows easy selection by the consumer and introduction of promotions of smaller sizes (25% extra for example). However, fruit must be of consistent quality within the pack or loss of consumer confidence will result in fewer repeat purchases.
- Over wrapping i.e. 4 or 6 apples in moulded trays sealed with cellophane, offers the opportunity to add value to fruit with enhanced attributes. For example for ready-to-eat (pre-ripened) fruit.
- MAP (modified atmosphere packing) which is commonplace in other product areas, usually by positive MAP (injected gases in the case of meat) is still in development for the apple supply chain.
- This technology has been tried in the past, but now improved permeable films offer an opportunity for MAP to become a standard procedure. This type of MAP will rely on a product-generated atmosphere using permeable films to establish and control the atmosphere inside the pack. Product will be packed into polybags and punnets.
- The benefit of this technology is a greatly enhanced shelf life, delivering enhanced texture to the consumer. The same technology will become commonplace in stone fruit and soft fruit as well.

Packing product into the final container (RDT or Pre-Pack unit)

- Assuming that grading has been carried out as described in the section on ‘post storage grading of fruits’, fruit will arrive at the final packing point for selection and packing into the RDT either as loose or pre-packed product.
- Before fruit is accepted onto the line, it should be assessed as suitable for the intended customer. This should be done by reference to QC reports carried out at the grading point and from a further assessment to confirm status before use.
- This assessment must involve confirmation of FTA readings (firmness), Brix levels (sugar) and taste acceptance (free of any taints etc.) as well as general quality criteria.
- Information on raw material quality onto the grading line will allow supervisors to ensure correct placement of packing line operatives and provide any relevant instructions. For example, a higher than normal proportion of apples that are marginal for shape or russetting requires extra vigilance on-line.
- Correct packaging and any associated labels should be confirmed and signed off by management in advance of the packing operation.
- All aspects of handling should be taken with extreme care. An apple can bruise as easily as an egg can break. All packing operatives should be made aware of the care needed.
- All staff should be clean and tidy, with short fingernails. If gloves are worn they must be of a suitable material and non-allergenic.
- Hygiene training has been dealt with in the harvest and handling section. Additionally, as a minimum, pack-house supervisors should have a certificate for Basic Food Hygiene Training.
- Induction training on health and safety issues should be a standard.
- An experienced trainer who, ideally, will have qualifications for training should give training in quality requirements.
- At the final packing stage operatives should be ensuring that fruit not only meets the customer specification but is also presented to maximum effect. As the market
place becomes increasingly competitive it is essential that presentation is maximised. This also applies to labels, whether on individual apples or on pre-packed product. Both should be positioned consistently and in compliance with customer requirements.

- Labels for pre-packed fruit must carry the information required by law and customer specification.
- Placement of pre-pack and over wrap packs into the ‘outer container’ is important on two counts. Firstly, to ensure that the product is packed in a manner that provides minimum risk from pressure marking (bruising against other packs or against the crate etc.). Secondly, to comply with customer requirements for presentation at the retail level.
- Most customer specifications require a particular arrangement of the packs within the crates and these should be tested in-house. Any detrimental effects on the fruit should be discussed with the customer via marketing/technical personnel.
- Where product is sold by minimum weight, all packed units must be weighed on DTIBERR approved scales. Trading Standards Officers will check these if they confirm any reported under-wights at the retail display level.
- The ability to demonstrate compliance with legal requirements will be a due-diligence defense if prosecution for under-weights takes place.
- Sufficient tare for any packaging materials used must be allowed for and added into the final pack weight, where minimum weights apply.
- The effect of moisture loss will result in reduction of packed unit weight from point of packing until its final acceptance point. This must be anticipated by adding sufficient tare to compensate for moisture loss.
- Most customer specifications indicate the required tare to accommodate moisture loss. This will vary between 10-30g per kg. This is sufficient for pre-packs but for loose product in a 12kg RDF (approximate 28lb) a 100g allowance may be required.

NOTE. UK Apples are generally sold by weight, using the Minimum Weight Regulations.

- Where automated polybagging machines are used that utilise weight and minimise giveaway weight, it is a legal requirement for machines that are not DTIBERR approved (stamped) that packs are check weighed on a separate DTIBERR approved scale before release for sale to the consumer.
- In pre-packs, sale by count is becoming popular. For trading standards purposes a consumer must be given a consistent offer. It is not permissible to offer 10 apples of 60-65mm one week, and then offer on promotion (indicating an increased value offer) 10 x 55-60mm apples (less weight) at a lower price the next week. The offer must be comparable.
- Average weight regulations are commonly used for products such as flour and sugar (fine ground) where an average weight (label depicts an ‘e’ mark) can be offered. For example a nominal 1 kg pack can legally fluctuate between 985g and 1015g, but must average 1000g. This is probably impractical for apples with average individual weights of 100g and would give no benefit to the grower/packer/supplier over minimum weight regulations.

Stacking fruit for optimum air flow and security

- When stacking boxes on pallets always try to optimise the flow of air between the boxes.
- In practice plastic crates, or any other RDF (cardboard) packed for a multiple customer will not allow any deviation from the basic 3 x 2 per layer and will need to be tight to each other for efficient transportation.
- Where an impact can be made is on early season fruit such as Discovery that is targeted for the wholesale market. Fruit quality will benefit from spacers between the boxes to allow air movement.
- Benefit would be gained also where fruit in market boxes moves quickly from the orchard into a cold store and then on to the marketplace in the same boxes.

Optimum pallet loading (full pallets)

- Optimising pallet loading will benefit quality and cost efficiency.
- Where part-loaded pallets travel long distances, transit damage will occur. On occasions this can result in fruit arriving below the customer specification and will result in rejection.
- Part pallets will often end up stacked on top of other pallets in transit. This increases the risk of damage.
- The optimum loading per pallet will depend on various factors:
  - Height of the pallet in relation to lorry height space. The longer the journey the greater the gain in quality and cost efficiency from maximum pallet height.
  - Health and safety regulations. Acceptable pallet heights must be determined by risk assessment.
- Multiple retailer customers will often operate different height restrictions. This is because risk assessment will take into account the circumstances in operating areas, which may be different. Receiving high load pallets may be possible if a system of de-stacking can be employed without risk of injury to operatives. Some companies may err on the side of caution when setting height limits.

Securing fruit on pallets

- Securing individual pallets will depend on the type of box used.
- Whichever type of box is used, careful alignment is paramount. Boxes overlapping the pallet, however slight this may be, or not tight to one another, will result in damage to the product and/or packaging at the destination. Even an unnoticeable appearance will impact on the saleability of the product.
- Cardboard RDF’s require corner boards and strapping. A minimum of 3 straps should be used at the top, middle and bottom of the pallet.
- It is important to maintain this format. If the bottom strap is too far up, it will result in the bottom boxes bowing and compressing. This will be exacerbated by damp air conditions.
- Corner boards may be used as a ‘belt and braces’ approach to secure plastic RDF’s. Generally they will be secured adequately by 2-3 plastic straps. Standard practice would be for the top strap to be on the penultimate layer and the lower strap on the 4th layer from the bottom.
- All plastic straps should be tight. This can only be achieved effectively with a strap tightener.
- Where pallets with fruit exposed (cardboard RDFs) are intended for the wholesale market, best practice should include the use of pallet covers. This will reduce the potential for soiling and in particular the risk of birds attacking the exposed fruit.
- Where fruit is intended for a multiple outlet and is conveyed through a closed system the use of pallet covers may not be necessary. This implies that fruit is loaded directly from the despatch store onto a lorry through closed system (docking bay) and unloaded again at a docking bay.
- If pallets with fruit exposed are not transferred by closed system best practice should include pallet covers. The cost of pallet covers is approximately 75p each.

Labelling boxes and pallets

- Labels should be printed and used in the packhouse in a tightly controlled manner.
- Before use, all new labels should be approved. This will involve the printer operator receiving a specification from the commercial manager. A specimen label should be printed and passed back to the commercial manager for checking and finally sending to the customer for approval.
- On a daily basis, the printer will check labels against the specification/specimen and print only sufficient for the intended order with 2 extra for label print records. The print number should be recorded in the label print records.
- Labels should be checked at the start of the print run and at the end of the run.
The British Retail Consortium (BRC) standard.

packing activities. However, the packing, environment and general procedures for all multiple customers and many higher profile wholesale customers require compliance with

The procedures of best practice indicated in the sections on British Retail Consortium (BRC) Standards

Shelf life assessment

On-Line QC inspection

Raw material assessment

As part of label information, full traceability must be maintained.

Final QC Inspection

Final QC Inspection should only be a confirmation of the status of the packed fruit.

If product at this stage of production is found to be below grade, clearly other QC inspections have failed. This is a serious issue and investigations should take place to identify where systems have failed.

Final QC inspection should take account of visual quality, fruit firmness using a FTA machine, edibility, label compliance including traceable information, pallet stacking and security.

Some multiples require final inspection to be a positive release formally signed off and shown on a positive release pallet label. This is taking the place of depot inspection and passing the responsibility to the supplier to ensure product fully complies with customer specification.

Shelf life assessment

Shelf life procedures allow the supplier to monitor a sample of despatched product. This enables a pre-warning of any issues of product deterioration, which may indicate a serious problem requiring withdrawal of product or possibly a reduced ‘display until’ period.

For example, where a product loses its condition before the ‘display until’ date, it will be beneficial to the supplier, retailer and consumer to reduce the period on display.

The supplier may choose the auditor from a list of accredited auditors.

Accredited auditors carry out audits of suppliers seeking to achieve the BRC standard.

The supplier may choose the auditor from a list of accredited auditors.

The code of practice covers all aspects of recognised best practice in product management systems.

The code of practice covers all aspects of recognised best practice in product management systems.

The supplier may choose the auditor from a list of accredited auditors.
The supplier bears the cost of audit expenses and the audit results are the supplier's property.

The supplier will authorise release of the audit reports to potential customers in support of any business agreement.

**Orchard management techniques**

**Orchard management techniques**

It is important that the impact of orchard management techniques on storage potential and eating quality are realised so that both higher productivity and good fruit quality can be achieved.

Sharplees (1973) carried out a comprehensive review of the many pre-harvest factors affecting the storage quality of apples. He separated the effects of permanent orchard factors such as soil type, rootstock and age of tree from the various management factors imposed by the grower.

The latter include different soil management systems, fertiliser application, orchard sprays, pruning, fruit thinning, etc. He also recognised that management practices were likely to change during the life of the orchard.

It is not possible within the scope of the Best Practice Guide to provide a comprehensive overview of the likely effects of every conceivable aspect of orchard management.

It is the intention to summarise the management practices that have the most significant influence on storage potential and eating quality. Much of the information contained in the review by Sharplees (1973) may be relevant today although there has been a major change in emphasis as regards the quality of fruit that is required.

Maximising storage life is no longer the primary requirement. To meet current market demands management practices need to be focussed towards achieving the desired visual and eating quality and to use storage technology to maintain that quality for as long as necessary.

Major changes in storage practices particularly the introduction of ultra-low oxygen and extreme controlled atmosphere (CA) conditions (ultra-low oxygen and elevated carbon dioxide) have done much to sustain the ‘season’ for home produced apples despite an inevitably reduced storage potential due to increased size and later harvesting. Pre- and post-harvest factors that affect the textural quality of Cox apples were reviewed more recently by Sharplees (1994).

**Cropping level, fruit size and thinning**

It has long been recognised that large apples are generally more susceptible to rotting and most physiological disorders than smaller fruit. However, in today's market, it is not an option to produce small fruit in order to maximise storage potential.

The challenge to the grower is to ensure that trees do not under- or over-crop and that fruit are not over-sized. Advice on achieving adequate initial fruit set and on subsequent thinning of the crop is provided in Part 1 of the Guide.

The level of cropping is not always within the control of the grower and low fruit numbers may occur in ‘off years’ in biennial bearing trees or due to adverse weather conditions.

The higher susceptibility of larger fruit to disorders such as bitter pit and senescent breakdown is related to the generally lower concentrations of calcium and higher concentration of potassium and magnesium.

Growers should be aware of the need to supplement the uptake of calcium into the developing fruit by the use of foliar calcium sprays and to ensure that samples are taken prior to harvest for an analysis of the mineral composition.

These actions are particularly required for lightly cropping trees and where the fruit size is large. Although increasing the size of apples may generally reduce storage potential there may be positive effects on the eating quality of the fruit.

Thinning Cox trees to remove all but the first axillary flowers or fruitlets increases the dry matter content of fruit at harvest and the firmness of fruit at harvest and after CA storage.

The greatest increase in firmness was achieved by thinning in the period 5-15 days after full bloom (FB) and to a lesser extent in the period 30-40 days after FB. In view of the risks associated with the thinning of flowers it may be appropriate to delay thinning until 35-40 days after FB.

In a recent MAFF Link (Agro-Food) project significant improvement in the texture of Cox apples was achieved in 6 commercial orchards by hand thinning to one fruit per cluster in late June (approximately 5 wks after FB).

Late thinning of the crop by hand may be impractical and too expensive and may not provide a sufficient increase in fruit size (see Part 1 of the Guide). A strategy of chemical thinning followed by hand thinning appears to be most appropriate and is likely to provide the size required for profitability whilst improving the eating quality of the fruit.

Clearly it is imperative that Cox and other dessert apple trees are not allowed to over-crop. This will produce too many under-sized and under-coloured fruit and will lead to a delay in harvest date in an attempt to improve these characteristics.

**Late harvest** will compromise the duration of storage.

The importance of adequate leaf area in relation to sugar content and colour development has long been recognised.

The adverse effect of over-cropping on red colour development is particularly acute in Jonagold orchards. Consequently adjustment of crop load by thinning is particularly important for this cultivar.

Early experiments on Delicious carried out in the US showed that it was possible to increase the area of solid red on apples from 23 to 58% by increasing the ratio of leaves to fruit from 10 to 75.

Concerns about light crops and oversized fruits relate primarily to cultivars such as Cox's Orange Pippin and Bramley's Seedling that are susceptible to calcium-deficiency disorders.

Other cultivars such as Gala normally achieve high concentrations of calcium in the fruit and for these there may be less of a concern that light crops may compromise storage potential.

**Rootstocks, pruning and shoot growth**

Effects of hard pruning on apple quality and storage potential are similar to those induced by light crops, either naturally or by thinning. Vigorous extension growth competes with the developing fruit for available water and mineral nutrients although fruits are well supplied with carbohydrates.

A high leaf to fruit ratio can lead to competition for minerals such as calcium and consequently to a higher incidence of calcium-deficiency disorders such as bitter pit.

It is also generally true that bitter pit incidence increases with increasing vigour of the rootstock. This is an important consideration when planting cultivars that are particularly susceptible to bitter pit such as Cox (various clones), Egremont Russet and Bramley's Seedling.
Removal of suckers and other vegetative growth can help to reduce the incidence of core flush and bitter pit. The benefits of early summer pruning in reducing core flush is illustrated by the results of trials in which early summer pruning reduced the incidence of core flush by 50% and 69% in air and CA-stored fruit respectively.

A number of commercial sprays are available to apply to the crop either before or during storage. Many of these have a fungicide component that are designed to protect against the development of core rot and other storage disorders.

There have been reports that the application of paclobutrazol and related growth regulators can reduce the incidence of both core flush and bitter pit. However, a number of trials have shown that the application of paclobutrazol can also increase the occurrence of core flush and the use of paclobutrazol for this purpose is not generally recommended.

The most effective way to control core flush is to maintain a high calcium level in the soil. This can be achieved by regular applications of calcium compounds or the use of orchard sprays containing calcium. However, the use of calcium sprays can be expensive and may not be practical in all situations.

Effect of orchard sprays

Relatively few types of sprays are applied to directly improve the storage quality of apples. Notable exceptions include the use of calcium and phosphorus sprays that are described elsewhere in this part of the Guide.

Most sprays are applied to protect the crop against the damaging effects of fungal diseases, insects and mites. Bioregulant sprays are also applied to apple trees for specific purposes such as increased fruit set, fruit thinning, fruit shape, improved skin finish or control of shoot growth. Clearly bioregulant sprays are applied to induce a physiological response in the tree or fruit and are therefore more likely to affect the physiology of fruits during the storage period than protectant sprays.

However, a number of fungicides are reported to have side effects that influence storage quality. Recent evidence has shown that the susceptibility of CA-stored Cox apples to diffuse browning disorder (DBD) is associated with the application of triazole chemicals that include the commonly applied fungicides myclobutanil ("Systhane" and "Aristocrat") and penconazole ("Topas" and "Topenco").

There have been examples in the past where bioregulant sprays applied during fruit development have resulted in major adverse effects on the storage quality of the fruit. The most notable example was the use of daminozide ("Alar") to control vegetative growth in Cox trees that resulted in a marked increase in susceptibility of stored fruit to core flush and breakdown.

With the exception of paclobutrazol ("Cultar") bioregulants currently permitted for use in apple orchards in the UK do not appear to cause adverse effects on storage quality. However it is true to say that without trials dedicated to testing effects of compounds or mixtures of compounds on storage and eating quality we may be unaware of possible adverse effects in the future.

In early trials the effects of paclobutrazol on storage quality were generally positive whilst GA4+7 ("Regulex") appeared to have no effect. However, fruit-setting hormones (GA3 + 2,4,5-TP), recommended where frost has destroyed a high proportion of flowers, had major adverse effects on the storage quality of Bramley apples.

Fruit thinning sprays are expected to have generally beneficial effects on eating quality through establishing the desired leaf to fruit ratio. However, over-thinning will result in oversized fruit and a high leaf to fruit ratio that is likely to result in increased susceptibility to calcium deficiency disorders.

In recent grower trials application of paclobutrazol induced DBD in CA-stored fruit from some of the orchards although triazole fungicides promoted DBD to a greater extent. The highest incidence of DBD generally occurred where paclobutrazol was applied in combination with triazole fungicides.

Restrictions on the use of triazole chemicals are advised for Cox and Meridian. Other cultivars with Cox as a parent may also be at risk but generally none of these are widely grown in the UK.

Products have been developed that regulate the ripening of fruit on the tree ("ReTainR", Valent BioSciences Corporation) or on the harvested fruit prior to storage (SmartFresh™, Landseer Ltd). Unfortunately, Valent BioSciences Corporation is no longer pursuing the registration of "ReTainR" in the UK. However, SmartFresh™ is fully approved for use on apples in the UK.

Soil management and mineral nutrition

The mineral nutrition of apple trees has a major influence on their growth and cropping and on the storage behaviour of the fruit. The latter aspect is dealt with in detail in Part 2 of this Guide.

Fertiliser and irrigation practice in orchards is likely to have a major influence on the uptake of minerals and water by the trees and on the mineral composition of the fruit. The choice of soil management system can profoundly affect the availability of soil nutrients to orchard trees.
The fertiliser requirement of trees in terms of their growth and cropping and assessment of the adequacy of fertiliser programmes to optimise these effects are beyond the scope of this section of the Guide, which deals only with implications for storage quality.

The paper by Greenham (1976) provides an important overview of the fertiliser requirements for fruit trees in England, although most of the experience on apple relates to Cox’s Orange Pippin in less intensive systems of production than are generally used today.

More recent work has focussed on the effects of soil management methods and nitrogen fertiliser application on the mineral composition and quality of stored Cox’s Orange Pippin and Braeburn’s Seedling apples.

Although application of nitrogen and the use of herbicides to reduce competition from grass and weeds may increase the yield and size of Cox apples, they may also produce softer fruit with a greener background colour and a lower content of alcohol-insoluble solids.

Whilst from the production view point increased area of herbicide use in orchards may be regarded as beneficial, it is important to recognise possible deleterious effects on eating quality.

The advice contained in the remainder of this Guide should enable growers to take advantage of practices that increase yield and fruit size whilst maintaining high quality in the market place.

Soil management has important effects on the concentration of phosphorus in apples. Inadequate levels of phosphorus in Cox and Braeburn apples increases the risk of low temperature breakdown (LTB) and may be associated with more rapid softening during storage.

The effect of grass sward in increasing phosphorus concentrations in Cox apples has been clearly established and consequently the use of herbicides to remove sward cover is associated with reduced phosphorus uptake into leaves and fruits.

Application of nitrogen fertiliser has similar depressing effects on phosphorus uptake. Growers should take every advantage from the higher productivity and lower management costs associated with herbicide management of the soil in orchards. However, the phosphorus levels in fruit should be monitored annually and remedial treatments such as foliar sprays containing phosphorus should be applied where fruit phosphorus levels are persistently low.

Although some other dessert cultivars such as Gala, Jonagold, Red Rippin and Spartan have an innately lower concentration of phosphorus in the fruit they are more resistant to LTB than Cox. Consequently the negative effects of herbicide use on phosphorus nutrition may not compromise the storage potential of these cultivars.

Effects of soil management treatments on susceptibility of Cox apples to bitter pit and senescent breakdown have been inconsistent. Effects of soil treatments on bitter pit development are generally related to effects on cropping and fruit size in any particular season.

Any increases in bitter pit potential due to soil management effects are likely to be ameliorated by application of calcium sprays and use of appropriate CA storage conditions.

Effects of soil management systems on the storage quality of Braeburn apples deserves special mention as the cultivar is highly susceptible to disorders such as superficial scald, bitter pit and LTB and overall grass is intensely competitive, reducing tree growth and yield and greatly decreasing leaf nitrogen.

Although fruits from trees grown in grass were higher in phosphorus and sometimes firmer and developed less bitter pit during storage, other quality characteristics were compromised including fruit size and background colour.

It is important to ensure that Braeburn trees are supplied with sufficient nitrogen, by reduced competition and fertiliser application, to maximise yield, fruit size and greenness. It is hoped that any increased bitter pit potential due to improved size will be countered by a full programme of calcium sprays and the use of stringent CA storage conditions.

Similarly the reductions in phosphorus content of fruits due to herbicide use and nitrogen application will need to be countered by orchard sprays containing phosphorus.

**Optimising the pre-harvest management of orchards to maximise the storage and eating quality of fruits**

**Orchard management practice** should always be geared towards maximum yields of class 1 fruit. The influences of such practices on storage quality need to be considered in order that appropriate marketing strategies can be put into place.

Where such practices adversely affect storage or eating quality, remedial measures need to be taken where these are available. The influence of pre-harvest factors on storage quality operate primarily through effects on yield, fruit size and vegetative growth.

**Cropping level, fruit size and thinning**

Large fruit from lightly cropping trees do not generally store well due to mineral imbalance in the fruit and to a low calcium concentration in particular.

Over-cropping trees produce small fruit that lack red colour and have insufficient dry matter for adequate texture, although the fruit is unlikely to develop physiological disorders associated with low calcium.

Judgement of the correct level of cropping to achieve sufficient yield, fruit size and visual quality without unduly compromising storage potential is paramount in achieving profitable production and commercial success.

**Adequate thinning** will help to ensure that harvest isn’t delayed beyond the optimum period for storage in an attempt to improve size and red colour.

Hand thinning Cox trees to one fruit per cluster at 35-40 days after full bloom has improved the texture and eating quality of CA-stored fruit.

Chemical thinning at the appropriate stage followed by hand thinning as necessary is the best practice to achieve the desired level of crop.

Thinning sprays may indirectly increase susceptibility of apples to calcium deficiency disorders such as bitter pit and senescent breakdown by increasing fruit size and the leaf to fruit ratio.

The priority should be the achievement of the correct level of crop for profitable production but awareness of the effects of thinning on the mineral status of the fruit is essential for planning storage and marketing.

The lighter the crop the greater the requirement for supplementing calcium nutrition of the fruit by the use of calcium sprays, post-harvest calcium treatments and of pre-harvest mineral analysis to predict storage potential.

**Pruning and shoot growth**

Vigorous growth competes with the developing fruit for available nutrients and water and can often exacerbate problems due to low calcium. Avoid hard pruning in the winter and use an appropriate chemical growth regulator as a means of controlling shoot growth in the spring and summer months.

Late summer pruning reduces susceptibility of stored fruit to bitter pit and other calcium deficiency disorders and improves red colour and the efficacy of calcium spraying in the orchard. However, this form of pruning should be limited to the vigorous upright one-year-old shoots and not done too early as re-growth may occur.

**Effects of orchard sprays**

Effects of the growth regulator ‘Cultar’ (paclobutrazol) on the storage quality of Braeburn apples have generally been positive but is known to induce diffuse browning disorder in Cox apples on some farms, particularly when used in conjunction with triazole fungicides such as myclobutanil or penconazole. Prohexadione (Regalis) may be the preferred growth regulator for use in Cox orchards.
Strategies for reducing ethylene in stored fruits

Ethylene gas is produced by apples during the process of ripening either on the tree or during storage. Ethylene, the ‘ripening’ hormone, triggers and co-ordinates many of the ripening changes that occur in stored apples such as softening and aroma development.

Storage under refrigeration and in controlled atmospheres reduces the rate at which these ripening changes take place. More effective control of ripening and a consequent improvement in fruit quality may be expected by further suppression of ethylene production by the fruit.

Ethylene removal is generally only worthwhile with unripe fruit therefore apples need to be harvested pre-climacteric i.e. before ethylene production rate of fruit on the tree increases.

Ideally all fruits should contain less than 0.1 ml l\(^{-1}\) of ethylene. It is easier to meet these requirements for Bramley than for Cox (or other dessert varieties). With the latter, picking fruit that is too immature may affect adversely its eating quality.

Bramley

The use of an ethylene converter is sufficient to control ethylene production in CA-stored Bramley apples without additional measures to inhibit production of ethylene. This is related to the immature state of the fruit at commercial harvest when compared with Cox and other dessert cultivars rather than an innately low production rate. Additionally the high concentration of CO\(_2\) (5-10%) used for the storage of Bramley suppresses ethylene production.

Beneficial effects of ethylene removal from Bramley stores include delayed development of superficial scald, firmness retention and reduced susceptibility to core flush. Ethylene scrubbing has no effect on chlorophyll loss (greenness) and does not affect acidity or sugar content of the fruit. There were no adverse effects on fruit quality resulting from the removal of ethylene from commercial stores of Bramley.

However, in other trials ethylene removal increased susceptibility of fruit to external CO\(_2\) injury. Consequently it is important to delay the establishment of CA conditions unless DPA is applied to the fruit prior to storage.

Requirements for effective ethylene scrubbing

- To achieve scald control in Bramley apples, maintain an ethylene concentration of less than 1 ml l\(^{-1}\) and ideally less than 0.1 ml l\(^{-1}\) in the storage atmosphere for most of the storage period.
- Ethylene removal systems for Bramley should be capable of maintaining 1 ml l\(^{-1}\) of ethylene in the storage atmosphere at an assumed rate of ethylene production of 1 ml kg\(^{-1}\) h\(^{-1}\).
- Fruit should not be late picked otherwise the ability to control ethylene production will be compromised. This may not be evident from measurements of ethylene concentration in the store atmosphere. Once the rapid phase of ethylene production is underway then removal of ethylene has little effect in slowing down ripening processes.
- The removal of ethylene from the storage atmosphere using heated catalyst scrubbers is a proven alternative to the use of diphenylamine (DPA) for delaying scald development.
- Growers can achieve control of scald for 6 months by attaching an ethylene scrubber to storage chambers where the carbon dioxide level is maintained at 8-10% by ventilation with outside air.
- Longer storage without scald development is possible where ethylene scrubbing is combined with low oxygen storage (5% CO\(_2\) + 1%O\(_2\)).
- In commercial trials no scald was evident in fruit stored in 5% CO\(_2\) + 1%O\(_2\) with continuous removal of ethylene when the trials were concluded after 10 months.
- DPA treatment is substantially more cost effective in controlling scald than ethylene removal.
- If the use of DPA comes under threat in the future then ethylene removal is a viable alternative strategy for scald control.
- Despite the effectiveness of ethylene scrubbing in controlling scald the use of heated catalyst systems may not be justified due to the high capital and running costs.
- Currently there are a number of alternative ethylene removal systems being tested on UK stores. These include low temperature catalyst systems, ozone generators and ethylene absorbents.
- Whilst growers will be interested in comparing the costs of these various ethylene removal technologies it is the ethylene removal efficiency that is of paramount importance.
- There is a need to compare the efficacy of current ethylene control technologies (chemical absorption, destruction by ozone or by a low temperature (photo-induced) catalyst) to enable growers to adopt the most appropriate method for their particular situation.
Cox’s Orange Pippin

Early harvesting plus effective ethylene removal can only achieve a delay in the onset of rapid production of ethylene but this can produce worthwhile benefits in the quality of fruit from store. However ethylene scrubbing without additional treatments to inhibit ethylene production will not slow the rate of softening during storage.

Inhibition of ethylene can be achieved by subjecting fruit to 15% CO₂ for 15 days prior to CA storage although this was found to induce the development of low temperature breakdown in the fruit late in the storage period. Subsequently 5% CO₂ for 15 days was found to reduce the risk of storage problems without affecting the beneficial response to ethylene removal.

The main benefit of ethylene scrubbing of Cox stores is reduced softening of the fruit although greater retention of acidity is also likely. There have been no effects of ethylene removal on the change in background colour.

- Although there are major quality benefits that can be achieved in Cox apples by removing the ethylene for CA stores the effects are inconsistent from year to year and between consignments.
- Ethylene production in Cox apples is higher than in Bramleys due to the fact that they are harvested closer to the point of ripening (initiation of rapid ethylene production) on the tree.
- For Cox stores the size of scrubber that is required and consequently the investment and running costs are increased by a factor of about 4 when compared to Bramley stores.
- Additional ‘conditioning’ techniques are required to reduce ethylene production in order to make ethylene removal effective which adds to the complexity of managing the crop during the early period of storage.
- Some ‘conditioning’ treatments such as pre-treatment with high levels of carbon dioxide may have deleterious effects on the fruit late in the storage period.
- Further developments in ethylene removal technology may improve the efficacy or cost-effectiveness of ethylene removal for Cox and may make it viable commercially.

Gala

Most of the work on ethylene removal at East Malling was done on Cox and Bramley apples. There are recent reports from Brazil that removal of ethylene from CA stores (3% CO₂, 1% O₂ at 1°C) containing Gala apples improves the firmness of fruits stored for up to 8.5 months. Low ethylene also maintained the appearance, background colour, crispness, juiciness and taste of stored fruit.

Strategies for control of ethylene production

Strategies that offer the prospect of improved control of ethylene production in apples include:

- Conventional breeding techniques - selection of genotypes with low production rates.
- Biotechnology - control of expression of regulatory proteins (ACC synthase and ACC oxidase) by genetic modification.
- Inhibition of regulatory proteins using pre-harvest bioregulants such as AVG (active ingredient of the commercial product ReTain® marketed by Valent Biosciences Corporation).
- Blocking the effects of ethylene using post-harvest bioregulants such as 1-MCP (active ingredient of SmartFresh® marketed by AgroFresh Inc., a wholly owned subsidiary of Rohm and Haas Co.).
- Inhibition of ‘feed-back’ effect using ethylene removal. Apples and other climacteric fruits are responsive to accumulating levels of ethylene. Effective removal of ethylene from the storage environment can delay the rise in ethylene production in stored apples.

Conventional breeding techniques

This strategy is essentially for the longer term and is not relevant to the improvement of existing commercial cultivars.

Biotechnology

This strategy has been demonstrated to be effective on the cultivar Greensleeves. Transformed clones grown in glasshouses at East Malling were found to markedly lower ethylene production rates than untransformed control trees. However, further work is required to transform cultivars that are important commercially in the UK and to restrict altered gene expression to the fruit only. There are important issues to be resolved as regards public perception and acceptance of this technology.

Pre-harvest bioregulants

This strategy presents an opportunity for the control of ethylene based on chemical inhibition. From 1997 to 2006 efficacy trials were carried out at East Malling in support of an application for registration of ReTain® for use as a pre-harvest spray to delay the onset of ethylene production and to delay / extend the harvesting ‘window’ for long-term storage.

Unfortunately the manufacturers of ReTain® (Valent Biosciences Corporation) decided to abandon their attempts to gain registration for their product in the EU.

Post-harvest bioregulants

SmartFresh®, a commercial formulation of the potent ethylene inhibitor 1-MCP, has been used increasingy by UK growers since the product was registered for use in 2003. Efficacy of the product was tested extensively at EMR from 2000 to 2003 and there is now considerable commercial experience of using the product.

Ethylene removal

This strategy can provide commercially important benefits to CA-stored apples although there are concerns that the technique may not provide consistent improvement and that scrubbing systems currently available may not be cost effective.

Prior to the advent of 1-MCP the possible use of ethylene scrubbing technologies had a greater significance. Whilst both these technologies are intended to maintain a low rate of ethylene production by the fruit in the case of 1-MCP the fruit is insensitive to ambient ethylene for a significant period after treatment whereas with ethylene scrubbing fruits remain sensitive to ethylene at all times.

The identification of storage disorders, causes and varietal susceptibility

Apples supplied to the market need to be free from internal or external disorders and should have limited potential to develop disorders during the period from retailing to consumption. Growers need to recognise early symptoms of disorders during the monitoring of their stores and to determine the likely progression by examining after a simulated marketing period.

Proper diagnosis of disorders is important in order to take remedial action in the future thereby preventing a recurrence of the problem. Images of the disorders of the flesh and of the skin described elsewhere in this Guide were also included in a wall chart (‘Apple Storage Rots and Disorders’) produced by the HDC and distributed to all registered
Classification of disorders

Symptom expression varies according to variety and storage conditions, and in most cases it is possible to make an accurate diagnosis on the basis of the photographs provided in this section. The disorders have been grouped arbitrarily into those that are visible externally and those that are visible on cutting the fruit. It is accepted that some disorders could be placed in either category. e.g. water core develops internally, but in some cases, particularly in Bramley apples, the disorder is visible externally.

Within each of the two main categories, three further categories of disorders are recognised. Firstly, those that occur as a normal consequence of storage; secondly those induced by the storage conditions and usually due to incorrect concentrations of carbon dioxide and/or oxygen; and thirdly, disorders associated with the application of post-harvest chemical treatments (external disorders only) or by mineral deficiencies in the fruit at harvest (internal only).

It is recognised that some disorders could be placed in more than one category. e.g. bitter pit and related disorders occur naturally during storage but are induced by mineral deficiencies in the fruit at harvest. Despite this, the following classification should be helpful to growers to recognise the disorders and determine the likely cause. The list is not fully comprehensive. Disorders that do not generally affect the more important commercial cultivars in the UK have been omitted.

Monitoring the condition of fruit in store

At least once a month assess the eating quality and internal condition of samples of fruit that represent the major orchards within a store. Once a store is opened, continue monitoring samples of fruit from all the major orchards regularly and check fruit quality remains above the customer’s specification.

Sampling

It is essential to examine stored fruit at regular intervals to check quality and internal condition. Representative samples need to be taken at harvest and placed in a bin under the store hatch.

- As fruit from each orchard is loaded into the store one sample should be taken for every proposed month of storage after October.
- It is important that samples are representative of the whole orchard and that there are sufficient samples to provide monthly monitoring of every orchard.
- Twenty apples are required per orchard per month. To obtain the samples for monitoring, one apple should be taken from every tenth bin from that orchard as it is being loaded into the store.
- If less than 200 bins from an orchard are going into the store, then fruit should be taken more frequently, e.g. sample every bin from a 20-bin consignment.
- The 20 fruits should be placed in a string net and labelled with orchard name, picking date and store number.
- This procedure should be repeated for each proposed month of storage after October, by taking apples from the same bins.
- The samples should be placed in a bin under the hatch and covered with a layer of fruit.
- If a second orchard is to be loaded into the store, fruit from another set of samples should be taken.
- Similarly, if fruit from a particular orchard is loaded into several stores then further sets of samples should be taken.

Fruit Assessment

Each month from October a sample of each store/orchard combination should be taken out and assessed.

- It should be remembered that the store atmosphere is lethal, and under no circumstances should anybody enter the store.
- The safety of the operator must be stressed.
- At no time should the operator place any part of his or her body in the store.
- People should always work in pairs, and use a ‘boat hook’ or similar extended hook to remove the netted samples.

Blemishes and disorders

Each apple in the sample should be carefully examined externally for any signs of blemish or storage disorders of the skin. Such disorders include lenticel blotch pit, carbon dioxide injury, superficial scald or damage due to calcium sprays or the use of a post-harvest drenching solution.

Colour

Colour is very difficult to quantify without the aid of sophisticated instruments. The skin of an apple is variable with patches of different shades of green and bleached areas where leaves have shaded fruit. With dessert apples, the stripes of red colour within the background colour makes it very difficult to assess.

A subjective method has been adopted in which the 20 fruits are laid out and, using a colour card as a reference (See Table 27 below), the overall background colour described as dark green, green, light green, light yellow or yellow.

The percentage of the surface area of the fruit coloured red is estimated for each fruit and expressed as a range. To ensure consistency, the light condition used should be good and the same for each assessment.

Firmness

Ten fruits from the sample should be selected at random for firmness measurements. Average values taken from month to month provide a general indication of the softening rate of stored apples.

The most widely used instrument for measuring firmness is the hand-held ‘Effigi’ penetrometer. For more consistent results this should be mounted in a drill stand and supported on a firm base. An 11 mm diameter probe should be used for apples and an 8 mm probe for pears.

The instrument should be calibrated against an accurate balance at least once a year. Fruit juice is very corrosive and thus the instrument should be washed, dried and coated in a thin mineral oil after use.

The following procedure should be adopted when carrying out the test:

1. Remove a thin slice of peel from opposite sides of each of 10 apples.
2. Lower probe into the flesh at a steady rate.
3. Take 2 seconds to travel 8 mm into the fruit.
4. Record value and reset.
5. Repeat on the opposite side of the fruit.

Where this procedure has been adopted little difference has been found in the readings obtained by different operators. However, to guard against any possible ‘operator error’ the same person should carry out the tests whenever possible. It is recommended that individuals using penetrometers should compare their results occasionally to
safeguard against any operating errors.

Disorders
The ten apples used for measurement of firmness are then examined internally for the presence of disorders of the flesh.

- A transverse cut is made close to the calyx end of the apple and the presence or absence of bitter pit or browning recorded.
- A second cut is made across the equator of the fruit through the core area and the cut surface assessed for core flush, low temperature breakdown and senescent breakdown.
- The severity of the breakdown is quantified by assessing the area of the cut surface affected. Slight is up to one third, moderate is between one and two thirds and severe above two thirds.
- During the examination fruits are tasted and scored for eating quality and the presence of any taints or ‘off-flavours’ should be noted.
- The remaining ten apples are placed in a room at 18°C and the external and internal condition assessed after seven days.

The mean fruit firmness, together with the percentage of fruit with various disorders, should be calculated and recorded on a purpose designed form. By using one form for each store/orchard combination the change in fruit quality or the development of storage disorders with time can be followed clearly.

Monitoring of Storage Conditions
Successful storage is a combination of the right fruit stored under the right conditions. If the temperature or oxygen is too high fruit will mature quicker and, if too low, there is a risk of damaging the flesh or fruit developing alcoholic taints. If the carbon dioxide is too high there is a risk of damaging the fruit, if too low the rate of change in background colour from green to yellow will increase.

It is therefore very important not only to check the fruit condition regularly but also the storage conditions. Computer based systems provide automatic control of storage conditions and are essential where low oxygen levels are being used. However the printed output generated from such systems is often difficult to interpret.

It is important that store operators maintain a manual record of store conditions. At least once a day the temperature, CO₂ and O₂ levels should be entered in a logbook using a separate page for each store.

This provides evidence that the storage conditions for each store have been checked each day and makes it easy to see overall changes in storage conditions during each month. During the monthly inspection of fruit samples the store logbook should be examined.

Fruit Quality Standards
All fruit in store should remain above the minimum quality standards required by the customer and have sufficient quality to allow for a seven day shelf life. WFL-Qualytech minimum standards are given in Table 27, but you should consult with your own marketing desk at the beginning of the season to ensure that information available is the most up to date.

Table 27. WFL-Qualytech minimum fruit quality standards. Firmness is defined in terms of an average for 10 apples and the minimum recorded for any of the individual apples within a 10-fruit sample

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Background Colour</th>
<th>Firmness (kg)</th>
<th>Soluble Solids (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Card 1, green - 4, yellow</td>
<td>Electronic Penetrometer</td>
<td>Refractometer</td>
</tr>
<tr>
<td>Cox</td>
<td>Green – Light Green (1-2)</td>
<td>Mean 6.5</td>
<td>&gt;12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn. 5.8</td>
<td></td>
</tr>
<tr>
<td>Gala</td>
<td>Light Green – Light Yellow (2-3)</td>
<td>Mean 6.2</td>
<td>&gt;11.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn. 5.8</td>
<td></td>
</tr>
<tr>
<td>Jonagold</td>
<td>Green – Light Green (1-2)</td>
<td>Mean 6.0</td>
<td>&gt;12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn. 5.5</td>
<td></td>
</tr>
<tr>
<td>Braeburn</td>
<td>Light green – Light Yellow (2-3)</td>
<td>Mean 7.2</td>
<td>&gt;11.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn. 6.7</td>
<td></td>
</tr>
<tr>
<td>Bramley</td>
<td>Green – Light Green (1-2)</td>
<td>Mean 6.5</td>
<td>&gt;12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn. 5.5</td>
<td></td>
</tr>
</tbody>
</table>

During the establishment of storage conditions Cox fruits may lose 0.5 to 1.0 kg in firmness. Subsequently the rate of softening in store depends on the oxygen level, the lower the level below 3% the slower the rate. Generally the following rates of softening have been found for Cox stored at 3.5°C:

- 5%CO₂ + 3%O₂: 0.3 – 0.4 kg per month.
- <1%CO₂ + 2%O₂: 0.2 – 0.3 kg per month.
- <1%CO₂ + 1.2%O₂: 0.1 – 0.2 kg per month.
**Post-storage management**

All CA stores should be opened before the fruit quality falls below the recommended standards and has sufficient reserve quality to ensure all product reaches the consumer in prime condition.

Provided there is not a seasonal high risk of low temperature breakdown, the temperature of fruit in Cox stores should be lowered to 0°C once opened. The rate that fruit softens is significantly reduced as the temperature is lowered.

Historically fruit store monitoring has been confined to netted samples placed under the hatch. However, once the store is opened the full extent of any bin to bin variation can be determined by sampling directly from a number of bins from each orchard.

The samples should be assessed as previously described and the results compared to the last netted samples. Samples should be taken from the bins at regular intervals until all the fruits from that store have been graded and delivered to the customer.

**Modifying tree nutrition for optimal storage quality**

Lime and fertiliser recommendations for apples are intended to ensure that availability and uptake of mineral nutrients do not limit growth and cropping. Soil and leaf analyses are used to determine general fertiliser requirements and to identify mineral deficiencies.

However, it cannot be assumed that a nutrient supply that is satisfactory for tree growth and cropping necessarily produces fruit with a satisfactory storage potential and eating quality. In many cases the availability of specific minerals needs to be restricted or supplemented in order to improve storage and eating quality.

Growers are advised to analyse soils, leaves and fruits on a regular basis in order to understand the full effect of their use of lime and fertilisers in specific orchards. These different types of analyses are necessary, as often there is a lack of association between fertiliser application and nutrient uptake or a poor correlation between nutrient levels in leaves and fruits.

There are many factors other than fertiliser application that affect the levels of nutrients in the leaves and fruits. Soil type, water availability, rootstock, pruning and cropping are some of the more important factors that influence uptake and partitioning of mineral nutrients within the tree.

**Practices that combine adequate cropping with good storage potential:**

**Nitrogen**

- In Cox orchards apply sufficient nitrogen fertiliser to achieve a maximum nitrogen concentration of 2.6% (dry weight) in leaves and 70 mg 100g⁻¹ (fresh weight) in fruit at harvest.
- In Braeburn orchards apply sufficient nitrogen fertiliser to achieve a maximum nitrogen concentration of 2.6% (dry weight) in leaves (M9 only) and a maximum nitrogen concentration 60 mg 100g⁻¹ (fresh weight) in fruit at harvest. Braeburn on M9/106 should have a maximum leaf N concentration of 2.6%.
- Economise on the use of nitrogen fertiliser by minimising grass/weed competition for water and nitrogen.

**Phosphorus**

- Supplement phosphorus nutrition in orchards where there is a history of flesh breakdown in stored fruit and where low phosphorus is implicated in the problem. Proprietary products are available for this purpose. These include 'Seniphos' (Yara Phosyn Ltd) that has proved particularly effective in raising phosphorus levels and reducing low temperature breakdown in Cox and Braeburn apples.
- In Cox orchards, achieve a minimum phosphorus concentration of 0.24% (dry weight) in leaves and raise leaf phosphorus concentrations in Braeburn to the higher end of the suggested range (0.18-0.22%).
- Apply phosphorus sprays in mid-June to mid-July to reduce susceptibility of fruits to breakdown in store. This is particularly important for Braeburn where a third of orchards achieve fruit phosphorus levels below the recommended threshold of 9 mg 100g⁻¹ (fresh weight).

**Potassium**

Potassium supply in orchards should be sufficient for adequate growth and cropping but major adverse effects occur during storage in fruit with excessive potassium.

- Potassium deficiency may be corrected by applying 3 sprays of potassium sulphate at 14-day intervals from petal fall. In Gala and Jonagold it may be appropriate to apply potassium nitrate if nitrogen levels are low.

**Calcium**

- The application of calcium sprays should be regarded as routine on Cox, Braeburn, Egremont Russet and Spartan. The effectiveness of the programme should be judged against mineral composition standards for good storage quality.
- In Egremont Russet, 110 kg hectare⁻¹ of calcium nitrate prills (79% calcium nitrate) per season is preferred in order to avoid leaf scorch associated with the use of the chloride form.
- In Cox, the nitrate form of calcium is preferred as fruit firmness is likely to be retained more effectively than with the use of the chloride form. Care is required in its application to avoid any tendon injury to the fruit.
- To derive maximum effect from calcium sprays, apply the full amount of material per season regardless of water volume and apply from June to as near harvest as is practicable. Minimise leaf scorch from calcium chloride by spraying in cool temperatures (<21°C) or by reduced spray concentration. Where spray rates are reduced increase the frequency of spraying. It may not be necessary to be as cautious about spraying in high temperatures when applying calcium chloride in water volumes of 100 litres per hectare or less.
- Proprietary products such as 'Wizal type Z' and 'Calcium Metasolate' have given improved results over standard flake calcium chloride when applied at equivalent rates of calcium per hectare. Other proprietary calcium products may provide similar improvements in efficacy but evidence should be provided to this effect before these are used in preference to calcium chloride (or calcium nitrate) and particularly where lower rates of calcium per hectare are advised.
- Foliar application of 'PreTect' is claimed by the manufacturers (Plant Health Care plc) to increase fruit calcium concentrations. Data provided showed calcium increases of 66% and 47% in Golden Delicious and Fuji apples respectively.
Magnesium

- Supplement magnesium nutrition where leaf analysis indicates sub-optimal levels or where there are visible symptoms of deficiency. Low magnesium in fruits may induce flesh breakdown in stored fruit whilst excessive levels increase susceptibility to bitter pit and related disorders.

- Two to five applications of magnesium sulphate (20 kg 1000 l⁻¹ ha⁻¹) applied at 14 day intervals provide a more rapid control of magnesium deficiency than soil applied forms of magnesium. It is important to offset any increased bitter pit potential from the magnesium sprays by subsequently applying a full calcium spray programme.

- Other proprietary products are available to rectify deficiencies of magnesium. Growers should consider the most appropriate material and method of application for their particular orchards in consultation with their advisers and spray representatives.

Boron

- Although boron deficiency can cause serious corking problems in apples, this is rare in the UK. There are adverse effects on storage quality that result from an over supply of boron. Analysis of soils, leaves and fruits should be carried out when boron deficiency is suspected.

- Boron deficiency can be rectified by soil application of materials such as borax (20 kg ha⁻¹) or ‘Solubor’ (10 kg ha⁻¹) in the spring or by 3 sprays of ‘Solubor’ (2 kg 1000 l⁻¹ ha⁻¹), with an appropriate wetter, starting at petal fall and repeated at 2-3 week intervals.

- Other proprietary products are available to rectify deficiencies of boron. Growers should consider the most appropriate material and method of application for their particular orchards in consultation with their advisers and spray representatives.