Preharvest factors affecting physiological disorders of fruit

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Abstract

Development of disorders during postharvest ripening and storage of fruit depends on a range of preharvest factors. The most obvious of these is maturity of fruit at harvest. However, a number of other factors may be just as important in ripening-related disorders and in determining how fruit respond to low temperatures or other imposed postharvest conditions. Fruiting position on the tree and fruit temperature history are two of the most important of these factors. In apples, position strongly influences fruit mineral contents, and consequently incidence of postharvest disorders such as bitter pit. This positional effect may reflect pollination and cropping effects, or more direct differences in flow of minerals and water into developing fruit. In both apples and avocado fruit, we have shown that high temperatures experienced by fruit on the tree can influence the response of those fruit to low and high postharvest temperatures. Specific disorders such as watercore in apples and chilling injury in avocado can also be related to fruit exposure to sunlight and high temperatures; disorders such as scald in apples may be related to frequency of low temperature exposure over the season. Identification of preharvest factors raises the possibility of producing fruit with less predisposition to postharvest disorders. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

There are few postharvest disorders of fruits which are completely independent of preharvest factors. Even incidence of disorders induced specifically by storage conditions such as low temperature or high CO₂ will be modified by preharvest environmental conditions and orchard practice. In terms of general postharvest product quality, this preharvest impact is implicit in the use of maturity indices for optimizing harvest times. Some preharvest factors may be effective through influencing fruit maturity. However, many direct effects of growing conditions and fruit development on postharvest disorder incidence may be quite independent.
In attempting to understand the relationships between fruit development and postharvest quality it is useful to divide disorders into those which are predetermined on the tree and those which are specifically induced by storage conditions yet modified by preharvest factors. The division may be somewhat artificial, although still useful, in that some disorders are in both categories.

2. Predetermined disorders

A number of fruit disorders, whilst recognized as postharvest problems, do not always require specific postharvest conditions in order to be expressed, and may be closely associated with the later stages of fruit development and ripening. Storage conditions (e.g. low temperatures, controlled atmospheres) may be used to ameliorate or delay disorder development or, in some cases, they can result in greater disorder expression.

In some well-studied disorders, such as bitter pit in apples (Ferguson and Watkins, 1989), the preharvest factors have been relatively well-defined. In others, they are largely still speculative. The factors affecting fruit development are mostly associated with either positional effects on the tree, or the environment. Examples of these are the interplay between position and nutrition, and responses of fruit to temperature changes or extremes.

2.1. Mineral nutrition, fruit position and crop load

Calcium is the nutrient most commonly associated with postharvest disorders. In bitter pit in apple fruit, almost all preharvest factors which influence incidence of the disorder can be directly or indirectly related to calcium nutrition of the fruit. The only exception may be maturity. The reason for the higher incidence of bitter pit in less mature fruit is not clear, but is perhaps related to subsequent rates of ripening (Ferguson and Watkins, 1989).

A number of preharvest factors are associated with movement of calcium into the developing fruit (Table 1). Apart from pollination, these are associated largely with relationships between fruit development, position on the tree, and the dynamics of nutrient flow in relation to leaves on the fruiting wood. Even where a very strong relationship between light crop load, low fruit calcium concentration and high bitter pit incidence is found (Ferguson and Watkins, 1992), the reason for this relationship may still lie in the position, leaf area and wood age of the fruiting site (Volz et al., 1993). Whilst we still do not have a clear reason for these positional effects, they will be associated with the ability of the spur and bourse leaves to draw calcium into the fruiting wood (Lang and Volz, 1993). The net result of these factors is that growers can minimize the risk of bitter pit incidence through appropriate orchard practice, and prediction schemes can be developed to segregate lines of high risk fruit.

Preharvest calcium nutrition of other fruits such as papaya and tomatoes has also been linked with subsequent postharvest quality and disorders. In papayas, low mesocarp calcium concentrations have been linked with fruit softening (Qiu

| Preharvest factors associated with increased incidence of bitter pit in apple fruit |
|---------------------------------|--------------------------------------------------|
| Low fruit Ca at harvest          | Ferguson and Watkins, 1989                      |
| High fruit Mg and K at harvest   | Ferguson and Watkins, 1989                      |
| Low crop load/low fruit Ca/high fruit K | Ferguson and Watkins, 1992; Volz et al., 1993 |
| Large fruit volume and weight/low fruit Ca | Ferguson and Watkins, 1989 |
| Poor pollination/low seed number/low fruit Ca | Bramlage et al., 1990; Tomala and Dilley, 1990; Brookfield et al., 1996; Volz et al., 1996b |
| Low spur/bourse leaf area/low fruit Ca | Jones and Samuelson, 1983; Proctor and Palmer, 1991; Volz et al., 1994, 1996a Schumacher et al., 1980; Volz et al., 1994 |
| Fruiting wood age and terminal or lateral positions | Ferguson et al., 1971; Ferguson and Triggs, 1990 |
et al., 1995), and in tomatoes blossom end rot has been associated with low calcium and high potassium fertilization of tomato plants (Ho et al., 1993). In these examples, as with bitter pit, the interplay between nutrient transport, water relations and fruit growth provides the basis for disorder susceptibility.

The influence of fruiting position and crop load characteristic of calcium-related disorders in apple fruit has also been shown with stonefruit. Incidence of mealiness and flesh browning in peaches has been found to be higher in fruit from trees with low crop loads, and higher in fruit from shaded, inner canopy positions (Crisosto et al., 1997). As more information is assembled, crop load and fruiting position seem to have as strong an effect on a range of storage disorders as any environmental influence. The two factors may be closely linked in terms of water and nutrient supply to the fruit.

2.2. Temperature and carbohydrate physiology

Watercore in apple fruit may be the most obvious disorder associated with dysfunction in carbohydrate physiology. It is a disorder which is often found on the tree and can decrease during storage or ripening (Marlow and Loescher, 1984). Incidence is associated with an increase in sorbitol in the extracellular volume of the fruit, and is likely to result from poor or dysfunctional transport of sorbitol into the cell. Although it is a generic disorder in some apple cultivars (e.g. ‘Fuji’), it does occur in others such as ‘Cox’s Orange Pippin’. Low levels of watercore may disappear during low temperature storage, and for some cultivars the affected fruit may subsequently develop internal breakdown (Perring, 1971). In terms of preharvest factors, the main influences include fruit maturity, fruit calcium levels, at least in the early development of the disorder (Bowen and Watkins, 1997), and fruit temperatures. Preharvest factors associated with other disorders, such as light crop loads, may also be associated with high watercore incidence (Faust et al., 1969). The disorder is thought to be of two types; the first is associated with late harvest and advanced maturity. Low temperatures during fruit matura-

![Fig. 1. Watercore in ‘Cox’s Orange Pippin’ fruit. Fruit were picked at commercial harvest (February 1998). (A) Symptoms associated with the core area and not related to exposed sides of the fruit. (B) Symptoms located on the exposed side of the fruit only. Arrows indicate direction of maximum exposure to direct sunlight when the fruit were on the tree.](image-url)
A disorder with many similarities to watercore is translucence in pineapple. This occurs before harvest, and can increase if fruit are stored (Rohrbach and Paull, 1982). Translucence has been related to high nitrogen, and high radiation, temperatures and rainfall during growth (Soler, 1994; Paull and Reyes, 1996). It also is more common in large fruit, a finding which suggests that it is related to fruit growth rates, and water and carbohydrate supply. High rainfall and the consequences on fruit growth also increase incidence of skin cracking disorders, such as found in cherries (Sekse, 1995), apples (Opara et al., 1997) and tomatoes (Whaley and Scott, 1997).

3. Storage disorders

The response of fruit to imposed storage conditions, principally low temperature, low O₂ and high CO₂, may well depend on preharvest growing conditions. In terms of specific disorders, there are a range of low temperature disorders which can be connected back to the condition of the fruit at harvest. Responses to altered gas concentrations in storage may be associated with maturity, cropping factors, skin and gas diffusion properties.

To prevent the occurrence of many of these disorders, one strategy has been to modify the storage condition which is responsible for inducing the disorder (e.g. raise storage temperature, reduce atmospheric CO₂ concentrations). However, this may sacrifice positive benefits from that storage condition. Knowledge of those preharvest factors which modify fruit responses to a storage condition is therefore important in optimizing product storage quality.

3.1. Low temperature disorders

Preharvest factors influencing postharvest chilling injury are mostly those to do with temperatures experienced during fruit development. Chilling injury of tomatoes (Lurie et al., 1993; Sabehat et al., 1996) and avocados (Woolf et al., 1995) can be reduced by heat treatments applied directly after harvest. By analogy, exposure to high temperatures on the tree, particularly close to or at harvest, may induce tolerance to low temperatures in postharvest storage. Flesh temperatures of avocado fruit growing in New Zealand, exposed to direct sunlight on the tree, frequently exceed 35°C (Woolf et al., 1999). These exposed fruit had lower levels of chilling injury than fruit from shaded parts of the tree, when stored at 0°C. Many fruits, not only tropical and subtropical, but also those growing under temperate conditions with relatively low (below 30°C) air temperatures (e.g. apples; Ferguson et al., 1998), can experience flesh temperatures in the range shown to be effective as postharvest heat treatments (35–45°C). We might expect in the future, therefore, to find more examples of chilling tolerance associated with preharvest high fruit temperatures.

One of the most studied postharvest disorders associated with low temperatures is superficial scald. This is a skin disorder linked to autoxidation of α-farnesene to conjugated trienes. It only develops after long-term cold storage, and it has been defined as a chilling injury (Watkins et al., 1995). At a physiological level, there are preharvest factors which predispose the fruit to the disorder (Emonger et al., 1994; Bramlage and Weis, 1997). The most direct relationship may be between greater incidence of scald in less mature fruit with low antioxidant to α-farnesene and conjugated triene ratios. High phosphate, low calcium and high potassium contents of fruit have been associated with increased scald incidence, although there is no clear direct physiological link. High nitrogen nutrition has also been associated with increased incidence, and there may be more direct connections between nitrogen and α-farnesene levels (Emonger et al., 1994). The shaded parts of fruit tend to develop scald more readily, suggesting a link with light intensity or temperature, and as with the heat effects just described, there is evidence that long-term temperature experience may influence subsequent development. From analysis of results collected over several years from four countries, Bramlage and Weis (1997) have concluded that reduced scald susceptibility in ‘Delicious’ apples can be related to relatively high amounts of preharvest low tem-
temperature exposure, rainfall and sunshine. Late season high temperatures resulted in higher susceptibility. The physiological reasons for these accumulated effects are not fully understood.

Some whole fruit and green plant tissues have been shown to withstand postharvest low temperatures better when conditioned by preharvest exposure to temperatures which are low, but above those which induce injury. Examples include grapefruit, sweet peppers and sweet basil shoots (Lang and Cameron, 1997, and citations therein). These results suggest some similarity between the effects of preharvest high and low temperature conditioning on tolerance to low temperature. There are suggestions that heat shock proteins induced by high temperatures have a role in both subsequent high and low temperature tolerance (Sabehat et al., 1996). Perhaps it is possible that proteins specifically induced by low temperature, and associated with tolerance, may have a longer-term effect.

3.2. Gas-related disorders

Fruit stored under controlled or modified atmosphere conditions are often subject to a range of disorders largely related to high CO₂ and/or low O₂ concentrations (Kader, 1997; Kupferman, 1997). In apples, the injury can be expressed both as internal browning (e.g. ‘Braeburn’) and as a skin disorder (e.g. ‘Empire’) (Watkins et al., 1997). There is considerable variation in incidence among seasons, regions and orchard lines, independent of maturity effects (Lidster et al., 1990; Watkins et al., 1997; Volz et al., 1998). Apples developing low O₂ injury, as a skin and/or internal disorder, can also show variation in susceptibility (Lau et al., 1987). Whilst there is a general presumption that preharvest factors are involved in susceptibility, there are not many examples of clear explanations for preharvest effects. For instance, the internal browning disorder found in ‘Braeburn’ apple fruit has been associated with high CO₂ and low O₂ concentrations within the fruit. It will occur on the tree and in air storage, indicating preharvest development or predisposition; disorder incidence is increased by CA storage (Kupferman, 1997; Lau, 1997; Elgar et al., 1998a). There is a strong harvest date effect on incidence, in common with many apple storage disorders, with later harvested fruit being more susceptible (Lau, 1997). However, a more specific preharvest factor not associated with maturity, is crop load, where light crop loads produce fruit with greater susceptibility (Elgar et al., 1998b). The reasons for this effect, so common with many disorders, are not understood. Watkins et al. (1997) have linked crop load, preharvest temperatures, and harvest date both with fruit respiration and skin permeance, and with more direct effects in predisposing fruit to CO₂ injury, but the physiological bases for these connections remain to be found.

4. Predicting disorder incidence

If preharvest development of predisposition to postharvest disorders is understood, then orchard practices which reduce risk can be developed (see Fig. 2). An additional benefit, particularly for marketing, is that such knowledge may provide the means for predicting potential incidence. If this can be done, then lines of products at high risk can be handled appropriately. Prediction can be based either on significant relationships between preharvest factors and postharvest disorder incidence, or on premature expression of the disorder by artificial means. The former have been the most successful.

Preharvest nutritional factors, such as those contributing to the strong calcium/bitter pit relationship, have formed the basis for commercial disorder prediction schemes which have been in use in New Zealand and other countries for some years (Ferguson and Watkins, 1989). While very significant biological relationships have been found, preharvest factors other than calcium alone have been introduced in order to make the prediction scheme more precise. In New Zealand, for ‘Cox’s Orange Pippin’ and ‘Braeburn’ fruit, this has involved incorporating magnesium and potassium levels, crop load, and fruit size (see Table 1). Nutrient levels, fruit
weight and density, have continued to be used and developed as preharvest factors in developing predictive systems for internal breakdown and bitter pit in apples (e.g. Wolk et al., 1998).

Preharvest environmental factors are being used to develop prediction schemes for scald in apples. Within a climatic location, temperature and maturity account for most of the measured variation in scald incidence (Bramlage and Weis, 1997). Any practical predictive system is likely to involve measurement of number of hours or days below critical temperatures over the growing season, frequent exposure to low temperatures being necessary to ensure a reduction in later scald development. Similar attempts to use preharvest temperature records to predict disorders are being made with pineapple translucence (Paull and Reyes, 1996), and the internal browning disorder in ‘Braeburn’ apples (Lau, 1997; unpublished New Zealand data).

5. Conclusion

Preharvest factors which may predispose fruit for subsequent disorder development are dominated by position of the fruit on the tree, characteristics of the fruiting site, crop load, mineral and carbohydrate nutrition of the developing fruit, water relations, and response to temperatures. Expression of disorders which are the direct result of storage conditions, such as low temperature and high CO₂, will still be modified by similar factors (Fig. 2). An understanding of these factors allows modification of fruit development to optimize storage quality, and development of methods for predicting disorder risk.

References


