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FACTORS INFLUENCING APPLE FRUIT FIRMNESS

Jennifer R. DeEll, Fadia Saad and Shahrokh Khanizadeh
Horticultural Research and Development Center, Agriculture and Agri-Food Canada
430 Gouin Blvd, St-Jean-sur-Richelieu, Québec J3B 3EB

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Fruit firmness is one of the most important characteristics of apple quality. Unfortunately however, it is also a characteristic that tends to be influenced greatly by many preharvest and postharvest factors. Obtaining and maintaining apple fruit firmness from the orchard through to the consumer, therefore, tends to be one of the major issues facing apple producers. Apples with a firmness of less than 4.5 kg (9.9 lb) are usually rejected by consumers and, therefore, this is the minimum acceptable firmness level for many soft cultivars (Prange et al., 1993). This article is a brief summary, with limited references as examples, of factors that have been shown to affect apple fruit firmness.

PREHARVEST FACTORS

Most apple quality characteristics, including fruit firmness, are genetically controlled and thus vary with cultivar. For example, Granny Smith apples are firmer than most other cultivars, whereas McIntosh apples are among the softest (Malenfant, 1998). The strain within a particular cultivar can also influence fruit firmness, such as standard-type McIntosh strains (e.g., Redmax and Marshall) which tend to be 0.45 kg (1 lb) firmer than the spur-type strains (e.g., Macspur) both at harvest and after storage (DeEll and Prange, 1994). Rootstocks may have an effect on apple firmness, but this tends to vary with cultivar and/or strain (Drake et al., 1993).

There are conflicting reports as to the relationship between calcium (Ca) content and apple fruit firmness. Bramlage et al. (1979) found McIntosh fruit firmness at harvest to increase slightly with increased flesh Ca concentration. However, the firmness of McIntosh apples does not appear to be influenced by preharvest sprays of $CaCl_2$ or other commercially available Ca mixtures (Bramlage et al., 1985). Similarly, preharvest $CaCl_2$ sprays do not affect the Ca content or fruit firmness of other cultivars, such as Wellspur Delicious (Davenport and Peryea, 1990). On the other hand, Golden Delicious, Delicious and Cox's Orange Pippin apples receiving Ca foliar applications have been shown to be 2.2 to 3.5 Newtons (0.5-0.8 lb) firmer than the respective nontreated apples (Raese and Drake, 1993; Watkins et al., 1989). In some cases, preharvest Ca sprays seem to be effective only when applied very often (18 times during the growing season) or at very high rates that would damage apple skin (Peryea, 1991; Weis et al., 1980).

Nitrogen (N) application does not appear to influence apple fruit firmness (Opara et al., 1997). However, high-N fruit tend to be larger, softer, more prone to preharvest drop, and more likely to develop physiological disorders in storage (Bramlage et al., 1980). Fruit size may be also correlated negatively with firmness at harvest and after storage. Boron (B) sprays do not appear to influence apple fruit firmness (Peryea and Drake, 1991), while some phosphate compounds applied as foliar sprays can improve fruit firmness of certain cultivars (Webster and Lidster, 1986).

Apple trees are sprayed with several sprays in order to control vegetative growth, hasten or delay ripening, delay apple abscission, and/or to simply enhance apple quality characteristics. However, many of these compounds also affect fruit firmness. The use of CPPU (N-(2-chloro-4-pyridyl)-N'-phenylurea, also known as fencloypr, KT-30, 4-PU and CN-11-3183) results in firmer fruit for some apple cultivars but not for others (Curry and Greene, 1993); SADH (succinic acid 2,2-dimethyl hydrazide, Alar™, B-9, or daminozide) generally results in greater fruit firmness but when other sprays (e.g., ethephon) are also used, reduced firmness may result (Greene et al., 1972); NAA (naphthaleneacetic acid) has little influence on apple fruit firmness (Marini et al., 1993); paclobutrazol generally results in firmer apples (Wang and Steffens, 1987); whereas AVG (aminoethoxyvinylglycine, ReTain™) tends to cause firmer fruit at harvest but the effect is lost during storage (Greene, 1996).

Other cultural practices such as crop density, root pruning, trunk scoring, and trunk ringing also affect apple fruit firmness. Apples appear to be slightly firmer when produced from trees with low crop density, compared to fruit from trees with high crop density (Opara et al., 1997). Fruit firmness may be also greater when apple tree roots are pruned, depending on the time of pruning (Schupp and Ferree, 1987). Trunk scoring and ringing may affect apple fruit firmness, depending on cultivar (Elfving et al., 1991). Water management also plays a role in determining fruit firmness. For example, fruits from nonirrigated apple trees may be firmer than those from irrigated trees, depending on cultivar and the type of irrigation (Opara et al., 1997).

POSTHARVEST FACTORS

Maturity at harvest can affect apple fruit firmness. Some apple cultivars (e.g., Golden Delicious and Redchief Delicious) show decreased fruit firmness with later harvest dates (Ait-Oubahou et al., 1995), whereas other cultivars (e.g., Starking Delicious) do not seem to be affected by harvest time (Sfakiotakis et al., 1993). Maturity at harvest can also affect the rate at which apples soften during storage. For example, earlier harvested Cox's Orange Pippin apples have greater firmness retention during storage than later harvested apples (Tu et al., 1997). Although ethylene production of apples is associated with increased maturity, fruit firmness is not necessarily related to ethylene production (Gussman et al., 1993).

Postharvest heat treatments, e.g., 38˚C (100.4˚F) for 4 days, have been shown to improve firmness retention of some apple cultivars during storage (Klein and Lurie, 1990). However, not all apple cultivars respond positively to prestorage heating. For example, holding McIntosh apples at 38 to 40˚C for 1 to 3 days results in firmness reduction (Chiu, 1984). Dipping heat-treated apples in a $CaCl_2$ solution tends to increase the effect of heating on firmness (Lurie and Klein, 1992).

Postharvest Ca dips or infiltration (e.g., 4% $CaCl_2$) increases fruit Ca content and reduces firmness loss for many apple cultivars (Mason et al., 1974; Sams and Conway, 1984). However, Ca uptake may vary enormously with apple cultivar (Lidster and Porritt, 1978) and rootstock (Pirmoradian and Babalar, 1995), as well as with different orchards and maturity at harvest for a given cultivar (Abbott et al., 1989). The source of Ca also influences its effect on apple fruit firmness (Beavers et al., 1994), and the addition of surfactants or thickeners to the Ca solution further improves firmness retention (Mason et al., 1975).

Other chemicals may also improve firmness retention in apples, even though that is not their primary use. For example, diphenylamine (DPA) is used to control storage scald, a physiological disorder of apple characterized by diffuse browning of the skin. However, DPA dips tend to also improve firmness retention (Lurie et al., 1989). The use of a sucrose fatty acid polyester (SPE) coating, also known as Semperfresh™, or diazocyclopentadiene (DACP), an inhibitor of ethylene-binding, also reduces firmness loss in apples (Blankenship and Sisler, 1993; Drake et al., 1987).

Temperature is the single most important factor governing the maintenance of postharvest quality, and therefore rapid cooling after harvest greatly improves firmness retention in apples during storage. Low storage temperatures are equally important, as McIntosh apples have been shown to soften as much as 20 times faster at 20˚C than at 0˚C (Lidster et al., 1988).

Many apple cultivars held in controlled atmosphere (CA) storage have improved fruit firmness retention and longer storage life. Standard CA conditions generally consist of 2-3% oxygen (O_2) and 2-4% carbon dioxide (CO_2), although for some apple cultivars low O_2 (1-2% O_2, 1-2% CO_2) is also used, and in some places even ultra-low O_2 (0.7-0.9% O_2, <1% CO_2) (Kupferman, 1997). CA storage, compared to ambient air, generally reduces fruit firmness loss by 14 to 20 Newtons (3-4 lb) after 4 months at 0 to 3°C; but this can be as high as 32 Newtons (7 lb) for certain cultivars (DeEll and Prange, 1992). Rapid CA establishment (within 4 days) further reduces firmness loss (Lau, 1983), whereas ethylene removal from CA rooms results in very little or no improvement in fruit firmness retention (Lau, 1989).

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