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Control of Pre- and Postharvest Factors to Improve Apple Quality and Storability

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Doctoral thesis

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Abstract

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To increase apple production in Sweden and to improve apple quality and competitive edge on the market, solutions to negative problems such as bruising susceptibility, decay and weak storage potential have to be discovered. This thesis investigated problems relating to apple quality and storability, based on the results of field and laboratory experiments conducted in Kivik, Sweden, during a period of 12 years. Four cultivars (Aroma, Ingrid Marie, Cox's Orange Pippin, and Katja) were predominantly used for the investigations.

The cultivar Aroma showed the highest internal phenol content and was the most sensitive to bruising, followed by cv. Ingrid Marie. Enhancement of water loss and melting of skin wax by air pre-cooling or post-harvest heating decreased the incidence of bruising. A significant negative correlation between skin colour and bruise susceptibility was found in some cultivars. Decay caused by *Pezicula malicorticis* was the most difficult problem during storage, followed by decay due to *Colletotrichum gloeosporioides* and *Penicillium expansum.* Cvs. Aroma and Ingrid Marie were more susceptible to decay than Cox's Orange Pippin and Katja. Post-harvest heating alone or in combination with ULO storage were possible alternatives to fungicides against these pathogens. Estimation of optimum nitrogen fertigation according to soil available nitrogen and fruit development phase not only increased tree yield but also improved fruit resistance to bruising and pathogens. Excess potassium increased yield and colouration, but declined fruit quality and storability. Aluminium foil or bark mulching improved fruit quality and increased storage potential. Apples from trees pruned in July or August showed a higher resistance to bruising and disorders and also better quality than apples from winter-pruned trees. Mulching and pruning solved the colouration problems present in cv. Aroma apples. Individual and twofold management models were not sufficient to improve the productivity of cv. Katja apples, whereas multi-practice management models improved yield, fruit quality and storability. The most positive effect was the reduction in quality decline during storage. The optimum harvest date was determined as the time when several fruit quality parameters changed similarly at a slow rate. ULO-stored apples (2% CO_2 and 2% O_2) showed less bruise sensitivity and decay, and also better quality than NA-stored apples. Fruit from young trees were less resistant to pathogens, had higher bruise sensitivity, showed better colouration and had a shorter storage life compared to fruit from older trees.

Keywords: Malus domestica Borkh, bruising, *Penicillium expansum*, *Pezicula malicorticis*, *Colletotrichum gloeosporioides*, mulching, pruning, fertigation, ULO storage, postharvest heating.

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Appendix

Papers I – VII

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Ericsson, N-A. & Tahir, I.I. 1996. Studies on bruising: Estimation of incidence and susceptibility differences in the bruising of three apple cultivars. *Acta Agric. Scand. Sect. B. Soil and plant Sci.* 46; 209 – 213.

II. Ericsson, N-A. & Tahir, I.I. 1996. Studies on bruising. The effect of fruit characteristics, harvest date and precooling on bruise susceptibility of three apple cultivars. *Acta Agric. Scand. Sect. B. Soil and plant Sci.* 46; 214 - 217.

III. Tahir, I. I., Johansson, E. & Olsson, M. E. 2005. Groundcover materials improve quality and storability of 'Aroma' apples. *HortScience* 40 (5); 1416-1420.

IV. Tahir, I. I., Johansson, E. & Olsson, M. E. 2005. Improving quality and storability of 'Aroma' apple by adjustment of some preharvest conditions. *Submitted.*

V. Tahir, I. I., Johansson, E. & Olsson, M. E. 2005. Improving productivity, quality and storability of 'Katja' apple by better orchard management models. *Submitted*.

VI. Tahir, I. I. & Ericsson, N.A. 2003. Effect of postharvest heating & CA-storage on storability and quality of apple cv. 'Aroma". *Acta Hort.* 600 (1); 127-134.

VII. Tahir, I. I., Johansson, E. & Olsson, M. E. 2005. Prediction of optimum harvest date for some apple cultivars. *Submitted.*

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1. Introduction

1.1. Background

The modern apple (*Malus domestica* Borkh.) is the product of hybridisation of *Malus sylvestris* and other *Malus* species. It belongs to the rose family (Rosaceae) and subfamily (Maloideae, x=17) (Brown, 1992). The floral tube, which is composed of the basal parts of the sepals and petals, fuses in the inferior ovary to form the fruit. The fleshy product contains five cavities, with two seeds in each one, and it is edible when it ripens.

The region of origin of the apple was southern Caucasian and it was found in Mesopotamia, Iran and East Asia many thousand years ago. The apple spread to Europe, where its cultivation was well known by the Ancient Greeks and Romans. In Greek mythology, Mother Earth (Gaia) gave the apple to Hera (the queen of the sky and earth) and her husband Zeus (the strongest man in the world) for their wedding (Erixon, 1999). The Roman Varro (ca. 100 B.C.) described the methods used for storing apples:

"It is thought that all apples keep well in a dry and cool place, laid on straw. For this reason, those who build fruit-houses are careful to let them have windows facing north and open to the wind, but they have shutters to keep the fruit from shrivelling after losing its juice, when the wind bellows steadily. And it is for this reason too – to make it cooler – that they coat the ceilings, walls and floors with marble cement. Some people even spread a dining table in it to dine there; and in fact, luxury allows people to do this in a picture gallery, where the scene is set by nature, in a charming arrangement of fruit" (Westwood, 1993. p.25).

As a consequence of colonisation, the apple was brought to North America, South America, Australia and Africa by the English, the French, and the Spaniards.

1.2. Production Areas

Asia has the highest apple production and the largest cultivated area in the world, followed by Europe, North America, South America, Africa, and Australia. The continents vary in their orchard productivity, and America has the highest rate (20-22 tons/ha), followed by Europe (18 tons/ha), Africa (13.8 tons/ha), Asia (11.5 tons/ha) and Australia (9.33 tons/ha) (Table 1). Although the leading countries in Europe as regards production in Mtons and cultivated area in ha are Poland, Romania, Germany, Italy and France, the highest orchard productivity can be found in Switzerland (50.67 tons/ha), The Netherlands (44.49 tons/ha), Belgium (44.11 tons/ha), and France (36.6 tons/ha). In Scandinavia, Denmark is the leading country, followed by Sweden.

1.3. Pomology Development in Europe

Research in pomology developed after the success of breeding programmes in England in the early 19th Century by Thomas Knight. The main aim of research during the 1950s and 1960s was to improve cultivation technology, to develop

Table 1. Apple production in European countries and in the five continents (FAO, 2005).

Country/Continent	Production (MT)	Area (thousand Ha)	Productivity (T/Ha)
Austria	352.52	13.00	27.11
Belgium	350.00	7.93	44.11
Bulgaria	27.00	5.39	5.00
Czechosl, Former	291.50	15.66	18.61
Denmark	32.00	1.65	19.39
Finland	2.80	0.55	5.09
France	2123.00	58.00	36.60
Germany	1600.00	70.00	22.85
Greece	247.00	15.50	15.93
Hungary	720.00	38.00	18.94
Ireland	500.00	0.60	25.00
Italy	2194.87	61.69	35.57
Netherlands	436.00	9.80	44.49
Norway	11.23	1.69	6.62
Poland	250.00	166.00	12.34
Portugal	246.00	20.00	12.30
Romania	478.09	72.74	6.57
Spain	797.70	41.28	19.32
Sweden	19.34	1.39	13.83
Switzerland	263.00	5.19	50.67
United Kingdom	160.00	9.00	17.77
Yugoslavia, Former	588.40	15.66	10.64
Europe	11717.21	634.10	18.48
Asia	34364.11	2995.52	11.47
Africa	2022.19	146.21	13.83
North America	5157.64	246.27	20.94
South America	4244.37	195.90	21.66
Australia	280.00	30.00	9.33

chemicals for tree protection and fertilisation, and to develop harvesting and cool storage systems for the fruit. During the 1970s and 1980s, more investigations were carried out concerning irrigation, fertilisation, and selection of new cultivars. The interest in using molecular biology and chemical ecology has increased in recent years. Increasing amounts of work to develop biotechnology in apples have been carried out in the last decade. The most important scientific task awaiting the researcher in coming years is production of organic apples of good eating quality and with high nutritional value.

1.4. Apples in Sweden

It is believed that apples formed part of the Viking diet, about 1000-1200 years ago. The Nordic myth says that the Goddess *Idun* had blessed the lofty apple which had protected the vitality of the God *Klenoder* (Erixon, 1999). In the mid of 14th Century, the first law was passed by *King Magnus Eriksson* to punish anybody stealing apples or damaging apple trees. *King Gustav Vasa* and his second wife, *Queen Margarita*, promoted apple cultivation around their castles. The queen asked her gardeners to give her a daily report about apple marketing in Stockholm in 1540. *King Erik XIV* was also very interested in apple cultivation. He and several nobles called in some foreign experts to develop Swedish apple cultivation. Priests and the church played an important role in the creation of apple orchards in the country, particularly in the Österlen area (Erixon, 1999).

The early studies of pomology in Sweden took place in the middle of the 19th Century, when Olof Eneroth performed numerous experiments with apples. An important book about apple production was published in Alnarp in 1929 by Carl G. Dahl (Dahl, 1929). During later years, two books have been published, illustrating information about 350 and 240 cultivars, respectively (Näslund, 2000; Svensson, 2003). We have to pay respect to the works of Carl G. Dahl, Emil Johansson, Åke Nyhlén, Ingevald Fernqvist, Nils-Arthur Ericsson, Torsten Nilsson, and Knut Sakshaug, which enhanced apple production in this country.

Apple production in Sweden covers about 1398 hectares and the total annual yield is 19 000-21 000 tons, which represents only 8-9% of national consumption (FAO, 2004). The low productivity, which is 70, 60 and 30% of the tree productivity in Denmark, Germany, and the Netherlands respectively (FAO, 2004), may be due not only to the short growing season and negative effects of low winter and variable summer temperature, but also to inadequate orchard management and post-harvest handling. Climate conditions are objective factors limiting the possibilities of choosing new cultivars with better productivity. Thus, increasing tree yield, maintaining fruit quality and improving fruit storage potential by adjustment of pre - and post-harvest factors are of great importance.

1.5. Apple Cultivars in Sweden

The most important cultivars in Europe are Golden and Red Delicious, Granny Smith, Gala, Morgenduff, McIntosh, Jonagold, Cox's Orange Pippin, Idared, Gloster and Elstar (Ferree & Warrington, 2003). In addition to the last five, other cultivars are produced in Sweden, such as Katja, Ingrid Marie, Aroma, Lobo, Alice, Gravenstein, Åkerö and Silva (Svensson, 2003). Production of cultivars showing high resistance to apple scab, such as Prima, Topaz, Saltanat, Santana, Eir, Wanda, Rubinola, Ella and Zarya Alatau, has started recently within the organic production system. In each part of the present study, one or more of the cultivars Aroma, Cox's Orange Pippin, Ingrid Marie and Katja was used (Table 2).

1.6. Nutritional value

The apple is low in calories, but it is a rich source of vitamins A and C, and supplies good amount of minerals (Table 3). It also contains several interesting compounds possessing possible health promoting abilities due to their function as antioxidants, or modulators of enzyme activity (Parr & Bolwell, 2000). Recent studies show that these bioactive compounds decrease the incidence of diabetes, cancer and heart disease.

Table 2. Important characters of the cultivars used in this study, (Näslund & Sandeberg, 2002).

Parameter	Aroma	Cox's Orange pippin	Ingrid Marie	Katja
Origin	Ingrid Marie and Filippa, 1973, Sweden	Seedling, Ribston 1825 in England.	Seedling 1910, Denmark	James Grieve and Worcest-erparmän, 1968. Sweden
Ground colour	Yellow	Yellow to green	Yellowish – green	Yellow
Cover colour	Red – yellow semi tender skin	Rusty red colour	Intensive red brown on the sunny side	Attractive red colour
Fruit flesh colour	White – yellowish Juicy	Yellow and juicy	Yellowish – white Juicy	White and juicy
Yield and storage period	About 14% of total production Sep. – Dec.	About 5% of total production Sept. – Feb.	About 35% of total production; Oct. – Feb.	About 2% of total production; Sept.-Nov.
Problems	Weak resistance to fungal decay and bruising	Effected by production systems	Weak resistance to fungal decay, cracks, and bruising	Very weak growth and early bearing

Table 3. Nutritional composition of apple (Westwood, 1993).

Compound	*Per 100 g edible portion*	*Compound*	*Per 100 g edible portion*
Water (%)	*84.8*	*Niacin B. vit. (mg)*	*0.1*
Calories	*56.0*	*Ascorbic acid, Vit. C (mg)*	*7.0*
Protein (%)	*0.2*	*Calcium (mg)*	*7.0*
Fat (%)	*0.6*	*Phosphorus (mg)*	*10.0*
Carbohydrate (%)	*14.1*	*Iron (mg)*	*0.3*
Vitamin A (I.U.)	*90.0*	*Sodium (mg)*	*1.0*
Thiamine B1 (mg)	*0.3*	*Potassium (mg)*	*110.0*
Riboflavin B2 (mg)	*0.2*		

Flavonoids, phenolic secondary plant metabolites, are widely believed to possess antioxidant, anti-microbial, anti-mutagenic and anti-carcinogenic properties (Koes *et al*., 1994; Shirley, 1996). Apples supply 7% of flavonoids (flavonols, flavones and anthocyanidins) in the European diet (Hertog *et al*., 1993; Lister *et al*., 1994). Dietary fibre prevents cholesterol to depositing in the linings of blood vessels and decreases the risk of colon cancer. Apple pectin is one of the main sources of dietary fibres (Cerda, 1988; Gheyas *et al*., 1998; Awad *et al*., 2000).

1.7. Apple quality

Consumer satisfaction, which is the main objective of the production, handling, storage and distribution of apples, is mainly related to their quality. Definition of apple quality varies along the production chain, depending on the purpose type of consumption. A lack of understanding of different perspectives may be the most limiting factor in improving the quality of fresh fruits and vegetables as delivered to the consumers (Shewfelt, 1999; Hoehm *et al*., 2005).

The term quality implies the degree of excellence of a product, comprising sensory properties (appearance, texture, taste and aroma), nutritional value, chemical constituents, mechanical properties, functional characteristics and defects (Abbott, 1999). Fruit quality can also mean the combined characteristics that determine their value to the consumer (Kader, 2002). Thus an acceptable apple must be free from mechanical damage, physiological disorders and pathological diseases. It must also be mature, firm, crisp, juicy and have a good flavour composition, which is a complex mix of sugars, acids and volatiles (Perring, 1989; Baldwin, 2002; Ferguson & Boyd, 2002). However, the influence of non-visual characteristics such as flavour, texture and nutritional value on the acceptance of apples on the market has increased in recent years (Awad & De Jager, 2003).

Consumers make their primary evaluation of apples on the basis of appearance (size, colour, form and absence of defects) (Kays, 1999). Fruit mass and volume increase during development. Large apples are not selected for storage due to their higher susceptibility to post-harvest physiological disorders (Sass, 1993). Thus, it is important to know what size category is suitable for the storage of each cultivar. Apple shape and form are not critical factors in the eventual consumer selection decision (Kays, 1999), whereas colour is still an important factor regarding fruit evaluation, because many people believe there is a close correlation between colour and overall quality (Marsh *et al.*, 1996; Kays, 1999). The red colour of apples is due to absorption of pigments of all wavelengths in the visible spectrum except for within the red region, which is reflected from the fruit (Sass, 1993; Kays, 1993). Apple colour changes markedly as fruits mature. Most cultivars lose their chlorophylls (green background colour) during maturation, whereas their yellow (revelation of carotenoids) or red colours (synthesis of anthocyanin) appear. Light and accumulation of carbohydrates are the essential bases of the synthesis of the red pigment Idaein (cyanidine-3-galactoside) within the skin fruit cell vacuoles (Westwood, 1993).

Total phenolic content declines throughout fruit development, resulting in a decrease in bitterness and astringency (Clifford, 1997). Acceptable quality also depends on the fruit aroma, which is caused by a large number of volatile compounds including alcohols, aldehydes, carboxylic esters and ketones (Dixon & Hewett, 2000). Starch is transported from source organs, and accumulates in fruit during development. Its hydrolysis before fruit maturation is the main source of fruit sugars (sucrose, glucose, fructose, and minor contribution of sorbitol), which are responsible for the sweetness (Knee, 1993). Organic acids (malic and citric acids) are other factors associated with fruit taste (Ferguson & Boyd, 2002). They are substrates of respiration and their levels decrease during ripening (Ackermann, 1992).

Apple texture is important in determining consumer acceptability. Several components affect this property, such as cell wall content and composition, particle size and shape, moisture and lipid content (Maini *et al*., 1985; Sams, 1999). However, softening is closely related to chemical changes in the pectin and middle lamellae (Kovacs *et al*., 1999). It is also positively correlated with fruit content of non-starch polysaccharides, and strongly correlated with the presence of galactose, glucose, arabinose, mannose and rhamnose in the hydrolysis of apple fibre (Gheyas *et al*., 1998).

1.8. Apple losses

Losses in fruit quality (such as loss in consumer acceptance or nutritional value) and quantity usual happen in the period between harvest and consumption. The loss quantity ranges between 5 and 25% in the developed countries and between 20 and 50% in the developing countries (Kader, 2005). An essential purpose of post-harvest physiology research is to reduce these losses. This objective can never be realized without a good understanding of the biological, environmental and practical factors causing these losses, and without the use of developed technology delaying fruit senescence processes and maintaining quality at an acceptable level (Hofman, 1998). Losses can be categorised on the basis of cause into three classes: Mechanical damage, physiological damage (storage disorders), and biological damage (insect and pathogen diseases) (Ferguson *et al*., 1999).

1.9. Mechanical damage to apples

Mechanical damage is unattractive to fresh market consumers and increases the incidence of fruit diseases during storage. It is caused by compression, impacts and vibration forces during one or more of post-harvest handling steps such as picking, loading, transportation, packing, sorting, storage and marketing. Compression forces can be exerted by the pickers, other apples, holders and consumers. Impact forces are exerted by mechanical handling systems, while vibration forces usually occur during transportation (Zhang, 1994).

The bruised area is often soft, brown and more susceptible to infections (Topping & Luton, 1986; Bruzsewitz *et al*., 1991; Topping & Luton, 1986). Fruit sensitivity depends on several factors such as cultivar, turgour, maturity, size, harvesting date, storage method, cultural practices, and post-harvest treatments. Fruits that are packaged in loose, rough, and dirty package containers with a thin bottom are more easily bruised (Schoorl & Holt, 1977; Lidster & Tung, 1980; Saltveit, 1984; Klein, 1987; Funt *et al*., 1999; Grajkowski *et al*., 2004).

Although the avoidance of bruise damage has been part of the design and operating strategy for all handling operations that take place between the tree and the consumer, the problem has been difficult to eliminate. Unfortunately, 100% of some Swedish apple cultivars are mechanically damaged during handling and transport from trees to consumers (Ericsson, 1989). To decrease the harmful effects of this problem on fruit quality, relationships between orchard conditions, cultivar characteristics, production area and storage methods should be investigated in greater detail.

1.10. Physiological disorders

Physiological disorders appear before, during and after storage, due to metabolic defects, which are caused by unsuitable environmental and nutritional conditions (Ferguson *et al*., 1999; Lafer & Brugner, 2002). Macronutrient and micronutrient deficiencies and accumulation of toxins result in many alterations in the colouration, shape and size of the fruit (Kays, 1999). They decrease fruit storage potential, competitive ability in the market and eating quality. The most important apple storage disorders in Sweden are:

1.10.1. Bitter pit

Small, brown, dry, and spongy spots in the flesh that appear through the skin as small circular, green or dark-brown depressed areas. This disorder develops after petal fall and is due to an active synthesis of protein and pectin together with greater movement of organic ions into the affected areas (Sass, 1993). It is related to all pre-harvest factors affecting the movement of calcium into the developing fruit. High position of fruit on the tree, low crop load, large fruit volume and weight, poor pollination, low spur and fruiting wood age can cause high bitter pit incidence (Ferguson & Watkins, 1989, 1992; Volz *et al*., 1994; Volz *et al*., 1996). Other conditions enhancing this disorder are hot, dry seasons and imbalance of water between fruit and leaves, which can cause moisture stress and reduce fruit calcium (Westwood, 1993). The mutual proportions of calcium, potassium and magnesium are thus of great importance. Calcium deficiency destroys the selective permeability of cell membranes, resulting in cell injury and necrosis. Accumulation of oxalic and succinic acids also dissolves the middle lamellae and causes changes in proton secretion (Andris *et al*., 2002). A mineral imbalance in the apple flesh with low levels of calcium and relatively high concentrations of potassium and magnesium produces the disorder.

1.10.2. Water core

This physiological disorder is associated with dysfunction in carbohydrate physiology, low calcium level and advanced maturity (Brown & Watkins, 1997). Two types of water core have been observed, one due to late harvest (Yamada *et al*., 1994); and the other due to exposure of fruit to high temperature or sunlight on the tree before maturation (Ferguson *et al*., 1998). The disorder is characterised by water-soaked areas near the core and around the primary vascular bundles in the apple flesh, which later develop into hard and glassy areas. Affected fruits are heavier than sound fruits and may be segregated by flotation in mixtures of water and alcohols, or by measuring light transmittance through intact fruits. Heat, drought, sunlight, calcium deficiency and over-maturity promote the disorder, which is associated with internal moisture stress, premature localised conversion of starch to sugar and pronounced sap leakage from cells, or an influx of sap into intercellular spaces. Sorbitol as a polyhydric sugar alcohol is translocated into the fruit from the tree before it has been converted to fructose by the apple fruit. Changes in cell membrane integrity cause an inability of the apple tissue to convert sorbitol into fructose, thereby resulting in an accumulation of sorbitol-rich solutions in the liquid of intercellular spaces, which causes the water core. Affected tissues show less gas exchange and more toxic materials (Westwood, 1993; Sass, 1993).

1.10.3. Soft scald

This disorder is a form of scald, characterized by sharply defined brown areas on the skin of the apple. The disorder can also extend into the flesh (Snowdon, 1990; Watkins & Rosenberger, 2002). Flesh tissues under affected skin are soft and discoloured to a slight depth, or to a deep brown flesh. The mechanism of the disorder is not known but has been related to oxidation of unsaturated fatty acids in the surface lipids and elevated hexanol concentration (Wills *et al*., 1981) and also may be related to abnormal respiratory metabolism in response to low temperatures during storage (Pierson *et al*., 1971). The other main reason of soft scald is over- maturity of fruit at harvest (Ferguson *et al*., 1998; Fan *et al*., 1999; Tong *et al*., 2003).

1.10.4. Internal breakdown

The disease is characterised by breakdown of the flesh on one side of the fruit or including the complete fruit. The flesh becomes off-white to yellow, then brown, spongy and mealy. Sometimes an outer narrow margin between skin and affected area stays sound. The skin is also discoloured, becomes dull and the fruit cracks. Internal breakdown is associated with old age. A close correlation with more intense respiration and calcium deficiency has been reported (Sass, 1993; Kays, 1999).

1.11. Fungal diseases

Pathological damage is caused by inoculation occurring prior to or during harvest. Degradation in appearance due to the pathogen occurs post-harvest or during storage. The degradation forms include undesirable alterations in shape and pigmentation, and failure to ripen (Kays, 1999). Fungal pathogens are the main cause of post-harvest losses of apples (Spadaro *et al*., 2004). Pre-harvest fungicide sprayings have only little effect on post-harvest rot, and no post-harvest fungicides are allowed in Sweden to control the fungus. Among the more than 150 fungal species observed around the world during fruit storage (Sass, 1993), four of them are of economic importance in Sweden: *Gloeosporium rot*, *Botrytis cinerea*, *Penicillium expansum* and *Monilia laxa or Monilia fructigena* (Haffner, 1993; Juhlin, 2003; Tahir, 2004).

1.11.1. Gloeosporium rot

This is a serious disease of apples. In Germany, 30% of cv. Topaz apples are destroyed by this problem (Maxin *et al*., 2005). The susceptibility to *Gloeosporium rot* increases with storage duration (Gualanduzzi *et al*., 2005). It is caused by several kinds of Gloeosporium fungus. The main kinds in Swedish apples are:

- Bitter rot: Caused by *Colletotrichum gloeosporioides*. Initial symptoms begin as small, slightly sunken lesions, 0.7-1.6 cm in diameter, which are light-brown to dark-brown. On mature fruit, lesions may be surrounded by a red halo. Rotten spots found after the fruits have been removed from storage are usually larger, more sunken and often produce wet pink or cream-colored spore masses (Borecka & Ceglowska, 1973; Sass, 1993).

- Bull’s eye rot: Caused by *Pezicula malicorticis*. Bull's-eye rot occurs in the orchard, begins at open lenticels or at breaks in the skin, and develops slowly at cold-storage temperatures, appearing on the fruits late in the storage season, during transit and on the market. The rot does not spread from one fruit to another. It can be light yellowish-cream or uniformly brown, but is most often brown with a pale centre that forms a bull's-eye. The spots are flat to sunken, and the rotted tissues are relatively firm. The skin over the surface does not break easily under slight pressure. The rot may be shallow or nearly as deep as it is wide. Decayed tissues are mealy and do not separate readily from the healthy tissues (Schulz, 1978; Juhlin, 2003).

1.11.2. Blue mould

This is also called soft rot of apples and is caused by *Penicillium expansum*, and usually appears at the end of storage. Affected fruits are characterised by a greenish-blue colour, changing to light brown on fruit with red skins and dark yellow to greenish-brown colour on fruit with yellow skins (Sass, 1993). The area becomes soft, develops rapidly and destroys the whole fruit. Later, under humid conditions, tufts of massed conidiophores with blue-green conidia appear on the surface of the fruit, which emits a characteristic musty odour. The pathogen is transmitted by air and soil-borne spores, especially in orchards. It commonly enters through wounds and injuries but may also penetrate lenticels (Onions, 1998).

1.11.3. Grey mould

This disease is induced by *Botrytis cinerea* and can cause serious economic losses in post-harvest storage (Jones & Sutton, 1984). The infected area is light-brown or sometimes dark-brown, slightly sunken and rot spots appear separated until they cover the whole apple. Then, mouse-grey cotton wool colonies develop on the fruit and the site of infection is soft but not soggy. On infected apples, *B. cinerea* sporulates, producing abundant conidia that can be dispersed by various means to healthy apples to incite new infections (Jarvis, 1977). The pathogen penetrates apple skin through injuries or orifices (Sass, 1993). Grey mould is difficult to control satisfactorily with fungicides because the fungus is genetically variable and has developed strains resistant to many of the chemicals introduced in the last 20 years (Staples & Mayer, 1995).

1.11.4. Brown rot

This is caused by *Monilia fructigena* and *Monilia laxa* and appears during storage as two forms. The first form is seen as large brown spots of rot, covered with concentric spore colonies ranging from white to brown. The second form is seen as brown spots, suddenly turning black and spreading to the whole fruit. The fungus penetrates the fruit through injuries or orifices on the skin, which might be caused by insect or any impact energy (Sass, 1993; Mordue, 1998; Spadaro *et al*., 2002).

1.12. Factors affecting fruit quality and storage potential

The first objective of fruit research is to increase yield and improve fruit quality at harvest. The next important goal must be to reduce post-harvest losses and maintain quality as far as possible during storage and marketing. The factors that affect fruit quality and storage potential can be divided into three groups:

1.12.1. Pre-harvest factors

Apple quality attributes are largely determined before harvest (Ferguson *et al*., 1999). Apples are grown worldwide wherever climatic conditions and soil are suitable. Production in areas with less than 500-600 mm precipitation or irregular distribution of precipitation throughout the season implies a need for irrigation. Temperature in summer and early autumn, cold nights and long light period with high light intensity play important roles in fruit colouration. Intensity of solar radiation can cause sunscald and result in loss in apple fruit quality associated with sunscald or sunburn (Watkins *et al*., 1993a; Westwood, 1993). Higher humidity causes apple scab and other fungal infections. However, apple adaptation to environmental conditions is closely cultivar-dependent. Many investigations have suggested that fruit quality and storability could be improved by adjusting orchard management practices such as mulching (Bhutani *et al*., 1995; Fausett & Rom, 2001, Vangdal & Hjeltnes, 2003), pruning, thinning (Tomala & Dilley, 1989; Raese *et al*., 1990; Ystaas, 1992; Warrington *et al*., 1995; Weinger & Wurm, 1998), and tree nutrition (Raese *et al*., 1990; Tomala, 1999; Jadczuk *et al*., 2001; Stampar *et al*., 2002; Ghosh *et al*., 2004; Soares *et al*., 2005). Such cultural practices affect fruit mineral composition, colouration, firmness, acidity and sweetness (Sharples, 1984; Tomala, 1999; Bound & Daniels, 2001; Ghosh *et al*., 2004; Soares *et al*., 2005) and also affect fruit resistance to bruising and pathogens (Bramlage, 1993; Conway *et al*., 1994; Basak, 1999).

Excessive irrigation decreases fruit firmness through increasing fruit size (Ebel *et al*., 1993) and causing subsequent weight loss during storage (Velickovic, 1992). Water is used as a medium for transport of nutrient to roots (fertigation) (Paoli, 1997) and therefore optimum nutrient availability depends on adjustments of the water applied (L´ubomir, 2001). Apple storability is highly dependent on the nutritional status of the apple tree (Faust, 1989). Reduction in biosynthetic capacity and insufficient reserves of photosynthesis products and nutrients indirectly affect the development of fruit. High nitrogen results in poor colouration and low fruit firmness (Blanpied *et al*., 1978) and correlates with soluble solids concentration (Fallahi *et al*., 1985). Potassium fertilisation can cause a decrease in firmness and crispness (Sharples, 1984). Excess manganese causes apple discolouration (Ferree *et al*., 1984) and low phosphorus decreases fruit firmness (Sharples, 1980). Calcium is directly involved in strengthening plant cell walls through its ability to cross-link with pectin through ionic association between C6 carboxyl groups of inter- and intra- galacturonosyl residues (Demarty *et al*., 1984). This role gives calcium its particularly important effect on fruit storability.

Fruit quality and storability are influenced by pruning because fruit firmness, colouration and content of calcium, sugar, flavonoids and anthocyanin depend on fruit position in the canopy (Tomala & Dilley, 1989; Raese *et al*., 1990; Ystaas, 1992; Volz *et al*., 1995; Warrington *et al*., 1995; Ferguson *et al*., 1995; Weinger & Wurm, 1998; Awad *et al*., 2000). Better pollination increases fruit calcium (Deckers & Missotten, 1993), whereas late fruit set decreases it (Link, 1993). Mulching improves fruit quality and storability due to improving soil conditions, tree nutrition and vegetative growth (Bramlage, 1993; Young & Sy, 2000; Rubauskis *et al*., 2002).

Unfortunately, some of these studies show contradictory results and mainly individual testing of each factor alone. Thus, the effects of different factors and their interactions need to be further studied in various countries and for different cultivars (Link, 1993).

1.12.2. Harvesting

Apple maturation can be divided into two stages; physiological and horticultural. Physiological maturity is the stage of development when fruits continue ontogeny even if detached. Horticultural maturity is the stage of development when fruits possess the prerequisites for utilisation by consumers for a particular purpose (Kader, 1999). Fruit ripening is an integrated series of changes that occur from the later stages of growth and development through the early stages of senescence (Sanz, 2005). This process is characterised by softening, higher sugar-acid ratio, better colouration, increasing respiration activity and internal ethylene production (Smith *et al*., 1979; Sass, 1993; Sekse, 1993; Lal Kaushal & Sharma, 1995; Willats *et al*., 2001; Peirs *et al*., 2002).

Respiration is a very complex physiological activity, where cell organic substances (mainly carbohydrates, but also lipids, proteins, and others) are decomposed to pyruvic acids, and these are later decomposed to carbon dioxide and water, through formation and disappearance of numerous intermediate products. This process involves a conversion of some oxidation energy into the energy of adenosine triphosphate (ATP) and a reduction in stored energy in the fruit (Sass, 1993). Apple is a climacteric fruit. The intensity of respiration drops sharply during cell enlargement and growth until it reaches a minimum. It then suddenly increases and reaches a peak, which is called the climacteric point, before it declines again. This continuous process deprives fruit of the energy, resulting in lower eating quality and storage potential, and then in collapse and decay of the cells (Westwood, 1993).

Apples produce internal ethylene before maturation. This production is followed by an increase in respiration rate. Ethylene gas plays an important role as a modulator of ripening even though it is present in very low concentrations. It is not only a ripening hormone, but also stimulates many reactions within the plant. Recent research has suggested that all apple quality parameters may be directly regulated by ethylene (Flores *et al*., 2001).

Selection of the optimum harvesting date is one of the most important ways to maintain fruit quality and minimise losses during storage (Henze, 1983; Sass, 1993; Sekse, 1993; Kader, 1999). Unfortunately, determination of the optimum harvesting date is not easy and depends on cultivar and environment. Because knowledge about the ripening behaviour of many cultivars is still limited, the optimal harvesting period of these cultivars has to be predicted as accurately as possible.

1.12.3. Post-harvest factors

1.12.3.1. Cold storage

The majority of apples must be consumed within a relatively short time after harvesting; otherwise there will be high rotting losses due to the biological properties of the fruit. Apples, which consist of living tissues, are submitted to continuous post-harvest processes, resulting in senescence and death (Kader, 1999). Since inhibition of these processes is not possible, decreasing the rate of them is an important task. Thus, the objective of storage is to prolong the life of the fruit tissues by slowing down the metabolic processes within the fruit that influence its age. Such metabolic processes include in particular respiration intensity and internal ethylene production (Paull, 1999). Both these processes are correlated with low temperature (Westwood, 1993). High storage temperature or low relative humidity or both reduce storage potential, decrease apple quality and enhance disorders (Robinson *et al*., 1975; Paull, 1999).

1.12.3.2. Controlled atmosphere storage

Controlled atmosphere storage (CA) and ultra low oxygen (ULO) storage, are the most important supplementary methods. The introduction of these storage methods has led to a real revolution for the assortment found in the fresh product departments of supermarkets. The techniques are essentially based on delaying the natural ripening processes by controlling the levels of certain gases found around and therefore within, fresh fruits and vegetables. Thus, the ripening process of apples meant for consumption can be postponed after their harvest in this way, without altering the product itself.

The respiration rate in picked fruit leads to reductions in the quality of the produce. The more frequently the atmosphere is exchanged, the more rapidly the deterioration in quality takes place. Thus, fruit storability can be improved by slowing down respiration. The substances expended and the enzymes that take part in respiration have to be found together in the mitochondria in the cell plasma and thereby the composition of the gaseous environment of the mitochondria influences oxidation processes, by regulating the functioning of enzymes (such as cytochrome oxidase, ascorbic acid oxidase, polyphenol oxidase) controlling the respiration process. The presence of a lower concentration of oxygen has an inhibitory effect on oxidative processes (respiration). ULO can also reduce or eliminate the detrimental effects of ethylene as a ripening hormone. In controlled atmosphere storage, a slow decomposition of polysaccharides into fructose takes place, and as a result, fruit flesh retains its firmness. The extent of carbon dioxide emission and oxygen utilisation, which can be regarded as a measure of metabolic activity, can be reduced to half or even a third of the normal value under favourable CA conditions. In this way, the ageing and decomposition processes slow down during storage, leading to a substantial prolongation of the storage period (El-Goorani & Sommer, 1981; Ben-Arie *et al.*, 1993; Goffings & Herregods, 1994; Capek *et al*., 1995; Phillips, 1996; Lau, 1998; Kader, 2003).

It is well known that ULO storage can be one of the post-harvest protection methods. The most well recognised gas with antimicrobial properties is CO_2 (Shewfelt & Purvis, 1995; Phillips, 1996). Its effect is complex and still poorly understood. High CO_2 with low temperature may increase solubility of CO_2 in water, which allows penetration of more bicarbonate ion into microbial cells and changes the cell permeability and metabolic processes. The CO_2 effect can be due to the capacity of the gas to inactivate amino acid binding proteins within the cell's periplasma (Phillips, 1996).

Due to the physiological basis of the ULO effect and fruit variety differences in several quality traits, high attention must be given to cultivar characteristics, cultivation region and orchard management, in order to obtain truly effective usage of ULO storage. Each fruit cultivar has an optimum level of storage atmosphere composition as a result of regional climatic differences. Unfavourable ULO conditions can induce physiological disorders (*e.g*. brown core), enhance susceptibility to decay, and shorten shelf life. ULO storage-related disorders include injuries due to high CO_2, low O_2 and reduction in post-storage volatile production (López *et al*., 2000; Fellman *et al*., 2003). Development of knowledge about the effects of ULO storage on fungal rots, bruise occurrence, fruit quality maintenance and the combination of ULO with other post-harvest treatments such as heating is an economic and scientific requirement (Vicente *et al*., 2003).

1.12.3.3. Post-harvest treatment

Warm fruit is generally more plastic than cold fruit and therefore has a better ability to withstand impact injury (Sommer *et al.,* 1960). Post-harvest heating of fruit enhances some of the ripening changes and attenuates others. The inhibition of ripening by heat may be mediated by its effect on the ripening hormone ethylene (Klein & Lurie, 1989).

Post-harvest heating has been used to control some diseases and maintain fruit quality during storage (Ferguson *et al*., 2000; Paull & Chen, 2000). Heated apples become firmer, have better flavour (higher SSC/acid ratio) and show better resistance to superficial scald than unheated (Klein & Lurie, 1992). Cell wall studies show that heated apples contain less soluble pectin and more insoluble pectin, as an index for inhibition of uronic acid degradation (Ben-Shalom *et al*., 1996). It has also been found that more calcium is bound to the cell walls of heated apples (Lurie & Klein, 1992). Inhibition of the synthesis of cell wall hydrolytic enzymes such as polygalacturonase and galactosidase during heating might cause firmer fruit (Sozzi *et al*., 1996). Another important explanation for the effects of post-harvest heating could be changes in apple skin structure. As is well known, apples are covered with a cuticle consisting of a cutine layer and a wax layer (Petracek & Bukovac, 1995). Cuticle protects the apple from infections, bruising and moisture losses (Jenks *et al*., 1995). The wax structure and chemical composition are cultivar-dependent. The cuticle appears flaked with shallow cracks (Veraverbeke *et al*., 2001). Early in the growing season, these cracks are quite deep and extend through the wax layer. By the end of the growing season, the epicuticular wax of non-heated fruit appears relatively smooth, but exhibits numerous surface cracks that form an interconnected network on the surface of the fruit (Faust & Shear, 1972; Roy *et al*., 1994). Temperature has been found to affect the quantity and structure of the wax and its crystalline shape. The epicuticular wax of heated fruit does not exhibit a network of cracks and the individual platelets of surface wax appear more randomly organised (Roy *et al*., 1994). However, post-harvest heating as a safe method to prevent apple decay has never been used in Sweden. The useful application of this method depends on a better understanding of its effectiveness, which varies according to several factors such as cultivar, heating application, degree, exposure period and harvesting date (Klein & Lurie, 1992; Roy *et al*., 1994; Klein *et al*., 1997; Lurie *et al*., 1998; Ferguson *et al*., 2000; Saftner *et al*., 2003; Conway *et al*., 2004).

1.13. Background to the present investigation

Today, there is an increased demand for a combination of attractive fruit, delicious taste and safe production process in the same apple. Early bearing and small fruit is one reason for the poor marketability of cv. Katja apples. Low resistance to pathogen and unacceptable colouration at harvest have the same negative effects on marketability of cv. Aroma apples. High production costs and rapid changes in the market have resulted in a difficult competitive position for Swedish apples which can only be resolved by production of fruit with high quality. This goal can be achieved by improving the use of pre- and post-harvest factors influencing fruit quality at harvest and after storage and/or shelf life (Terlouw, 2003).

1.14. Objectives of the investigation

The main aim of this work was to solve some problems concerning the storability (bruising, physiological disorders, fungus decay, and depreciation of fruit quality) of some apple cultivars. Specific aims were to:

1. Study the sensitivity of three cultivars (Aroma, Cox's Orange Pippin, and Ingrid Marie), to bruising and changes in damage during storage, and determine better accurate method of quantifying bruise occurrence.
2. Study the effects of several factors such as harvesting date, air pre-cooling, post-harvest heating and fruit size on the occurrence of bruising.
3. Compare the effects of herbicides and mechanical cultivation with the effects of three ground cover materials (bark, aluminium foil, polypropylene) on tree yield, apple quality and fruit resistance to bruising and pathogens.
4. Study the relationships between tree nutrition (nitrogen fertigation and optimum potassium fertilisation), tree age and pruning time, and fruit quality and storability of apples.
5. Investigate the influences of 36 different management models on tree growth, yield, fruit quality and storability of apples.
6. Study the effects of post-harvest heating and ULO storage as alternative methods to fungicides in terms of fruit storability and quality maintenance.
7. Determine the ripening behaviour of apple cultivars (Aroma, Cox's Orange Pippin, and Ingrid Marie), and determine their optimum harvesting dates, in order to maintain fruit quality and improve storability.

2. Materials and Methods

2.1. Pre-harvest factors

2.1.1. Mulching

2.1.1.1. Cv. Aroma apples *(Paper III):*

Eighty trees were used to compare the effects of two conventional mulching methods (herbicides and mechanical cultivation) with the effects of three ground cover material systems (GCMS) (black polypropylene, bark and aluminium foil) during seven seasons. Herbicides (a mixture of glyphosate and Dikvat or MCPA) were sprayed onto the soil twice a year (May and July) and soil was tilled monthly (May-August) by rotary hoe or rotavator. Ground cover materials, including black polypropylene bark and aluminium foil, were added every season. Treatments covered the soil as far as one metre on both sides of the trees.

2.1.1.2. Cv. Katja apples *(Paper V):*

Two treatments were carried out: Application of herbicides (a mixture of glyphosate (360 g/L Roundup. N-phosphomethylglycine) and MCPA (Duplosan super, 4-chloro-2-methylphenoxy) and mulching orchard ground with a layer of bark.

2.1.2. Pruning

2.1.2.1. Cv. Aroma apples *(Paper IV):*

Ninety-six trees, on rootstock M26, were pruned on different dates during four seasons. Pruning treatments included: All upper and side shoots were removed in March; all upper shoots were shortened to 30 cm and all side shoots either removed or shortened to 30 cm after three weeks of flowering; all shoots shortened to the 7^{th} leaf in the middle of July, or in the middle of August, or in early September; and pruning both in March and July.

2.1.2.2. Cv. Katja apples *(Paper V):*

Two pruning systems were applied on twelve cv. Katja trees during four seasons: Standard pruning whereby all shoots on the tree top and sides were shortened to about 30 cm long in early April of each year; and radical pruning whereby two thirds of each top shoot were pruned and all lateral shoots were totally removed or shortened to 5-10 cm in early April of each year. Starting in the second year, all shoots were shortened (weaker removed) again in mid-July, to the nearest bearing shoot.

2.1.3. Tree nutrition

2.1.3.1. Cv. Aroma apples *(Paper IV):*

2.1.3.1.1. Adjustment of **nitrogen** fertigation according to soil nitrogen content and different season periods. The growing season was divided into four vegetative periods of four weeks each, starting at full bloom. Soil analyses were carried out monthly and soil nitrogen content was determined and classified as one of three groups: low soil N (soil which contained less than 25 kg/ha), medium soil N (soil which contained 25 kg/ha), and high soil N (soil which contained more than 25 kg/ha). A lot of 96 trees was divided into four blocks and fertigated with four different amounts of nitrogen according to vegetative period and soil nitrogen content. All trees were sprayed 8 times per season with Ca. The experiment was conducted during four years.

2.1.3.1.2. **Potassium** fertilisation was adjusted by selection of 60 trees, fertilising them with one of five different systems: Drip irrigation 0.8 l/tree/day; standard fertigation with Red Superba and Gartnersalpeter, 1:200 (NPK 7-4-21 with Mg, S, and micro nutritional elements); standard fertigation + 300 kg/ha potassium sulphate; standard fertigation + 600 kg/ha potassium sulphate; and standard fertigation + 900 kg/ha potassium sulphate. Potassium fertiliser was applied on soil annually in February.

2.1.3.2. Cv. Katja apples *(Paper V):*

Eighteen trees were fertigated by standard fertigation levels, 0.13 g of Red Superba and Gartnersalpeter, 1:200 (NPK 7-4-21 with Mg, S, and micro nutritional elements), during the period May-August. Two thirds of the fertigated trees received excess nitrogen (one dose of 25 g CalciNit (15.5% N and 19.0% Ca), applied on 1 May, and half of these excess fertigated trees received additional nitrogen (one dose of 25 g CalciNit applied on 1 June).

2.1.4. Tree age (Paper IV):

Twelve homogeneous trees for each of three different ages (young trees (4-6 years old), middle-aged trees (6-20 years old) and old trees (older than 20 years) were investigated during six seasons. To increase the variation in fruit quality and avoid crop load effects, 50% of trees were hand thinned.

2.1.5. Thinning (Paper V):

Eighteen cv. Katja trees were selected and divided into three groups. One group was left without thinning and the other was partially thinned whereby one bud per shoot was left to develop. The third group was totally thinned, whereby all buds were removed.

*2.1.6. Orchard management models (Paper V)***:**

In the experiments above, cv. Katja trees were treated by individual practices such as pruning, mulching, fertigation and thinning. In this part, thirteen twofold management models (with two practices each), twelve threefold models (with three practices each) and fourfold model (with four practices each) were created and applied during four years.

2.2. Determination of optimum harvesting date (Paper VII)

During ten seasons, fruit of cvs. Aroma, Cox's Orange Pippin and Ingrid Marie were picked three times a week, from both outside and inside twelve trees of each cultivar. Different maturity indices, such as starch content, soluble solids concentration, titratable acidity, flesh firmness, skin colour, internal ethylene concentration and respiration activity, were determined for each harvest. Fruit were picked at six different times a season and stored in cold and ULO storage.

After storage and an additional shelf life of 7 days at 20 ºC, fruit quality parameters were analysed again and the incidence of physiological disorders and fungal rots was determined.

2.3. Post-harvest factors

2.3.1. Pre-cooling (Paper II):

During two seasons, fruit of three cultivars (Aroma, Cox's Orange Pippin and Ingrid Marie) were pre-cooled by a current of cold air (3-4 ºC) for 36 h before bruising.

2.3.2. Heating (Paper VI):

Healthy fruit, free of mechanical damage, were harvested on the optimum date and divided into five groups. The first group was stored without any treatment. The second group was covered with polyethylene foil and kept in small chambers, at 20, 30, 40 °C or 90% RH. for 24, 48, 72 or 96 h. The third and fourth groups were subsequently inoculated with a conidial suspension of *P. expansum* and *P. malicorticis* and *C. gloeosporioides* before and after heating as the second group. Fruit from the fourth group were divided into two subgroups, one bruised directly after harvest and the other bruised after heating at 30 °C for 24 h. All groups of fruit were stored in cold and ULO storage.

2.3.3. Vinegar treatments:

Cv. Aroma fruit, healthy and harvested on the optimum date, were inoculated with conidial suspensions of *P. expansum*, *P. malicorticis* and *C. gloeosporioides*, and left at room temperature for 3 h. Thereafter, inoculated apples were placed in a sealed chamber which was supplied with small fans, for 30 min. Vinegar was dripped onto paper and vaporised by heat of an aluminium receptacle (Sholberg *et al*., 2000). Vinegar vapour treated apples were stored in cold storage for four months.

2.3.4. Fruit inoculation (Paper VI):

Fungi were isolated from decayed stored apples and used to inoculate Petri dishes with potato dextrose agar (PDA), which were incubated at 25 º C, for one week. A conidial suspension was separated in Tween 80 (0.05 %, w/v) in water and diluted to 104 conidia ml^{-1}. Apples were wounded on two opposite sides to a depth of 2 mm by pressing them down on the head of a nail 2 mm in diameter. The wounds were inoculated by aqueous suspension of either *P. expansum* or *P. malicorticis* and *C. gloeosporioides*.

2.3.5. Cold storage (Papers II – VII):

In all experiments, fruit were stored within 24 h of harvest in new plastic boxes, using storage chambers which were cooled by air to 2 ºC (± 0.5), and their relative humidity was adjusted to 90-92%.

2.3.6. Control atmosphere storage (Papers VI and VII):

Fruit were stored within 24 h of harvest in small chambers (1-2 m^3) that were placed in a cold storage room, 2 (± 0.5) ºC. The desired atmosphere in the chambers (2% CO_2 and 2% O_2) was adjusted by computer, and automatically generated from cylinders of N_2 and CO_2.

2.4. Evaluation:

2.4.1. Bruising (Papers I – IV and VI):

2.4.1.1. Bruise occurrence: Fruit were bruised once by dropping them on their cheek from different heights onto a wooden table, marking the impacted area, and leaving for several hours.

2.4.1.2. Bruise quantification methods: Different bruise susceptibilities were quantified by one of the following methods:

- Numerical parameter: Number of bruised areas on 100 fruit.
- Diameter parameter: Percentage of bruise diameter to fruit diameter.
- Bruise weight parameter: Percentage of bruise weight to fruit weight.
- Bruise volume parameter: Percentage of bruise volume to fruit volume.

2.4.2. Vegetative growth (Papers III – V):

Increase in trunk cross-sectional area (TCSA = (stem diameter/2)^2*Π) at 30 cm above the graft during the period March-April of each season was used to estimate the vigour of growth. The effect of crop load was also estimated (crop load = number of fruit/TCSA). Another growth index was used whereby five shoots were marked randomly in each crown, and changes in their length during the period May-September were measured.

2.4.3. Yield and fruit weight (Papers III – V):

Each tree yield was weighed and recorded and the main yield/ha and total fruit weight were calculated.

2.4.4. Quality parameters (Papers II – VII):

Fruit quality was evaluated at harvest, after storage and after shelf life. Fruit firmness was determined by a penetrometer (model FT 327, Effigi, Alfonsine, Italy, plunger diameter of 11.1 mm, depth of 7.9 mm) on opposite sides of each fruit and the results were expressed as kg/cm^2 or Newton. Soluble solids concentration (SSC) was measured by a refractrometer (Atago, Japan) and the results expressed as ºBrix. Titratable acidity (TA) was analysed by titration of fruit juice as malic acid with 0.05N NaOH to pH 8.1 (Radiometer PHM64-Danmark) and the result expressed as a percentage. Fruit colouration was measured through the hue angle using a colorimeter Chromameter, model CR200 with 8 mm diameter window (Minolta Camera Co, Ltd. Osaka, Japan). Measurements were conducted on three spots per fruit, and expressed as h°, *i.e*. hue angle (where 0° = red-purple, 90° = yellow, 180° = bluish-green, and 270° = blue) (McGuire, 1992). Starch score was evaluated by dipping a slide of the fruit, cut at the equator, into an iodine solution (15 g potassium iodide and 6 g iodine per litre) for 1 minute, and using a grading scale where 1= full staining, 2= clear of stain in seed cavity, 3= clear of stain in halfway to vascular area, 4= core nearly free from staining, 5 = core free from staining, 6= clear through the area including vascular bundles, 7 = half of flesh clear, 8 = staining just under skin, and 9 = free of starch (no stain)

(Ericsson, 1982). Streif index was calculated as: Streif index = Firmness (kg/cm^2) / (SSC (% Brix) * starch (degradation stage) (Streif, 1996).

2.4.5. Storage decay (Papers III – VII):

The percentage incidence of some physiological disorders (soft scald, bitter pit, water core and internal breakdown) and storage rots (*P. expansum* or *P. malicorticis* and *C. gloeosporioides*) was determined by visual examination after storage and shelf life. Disorders and type of pathogens were determined according to Rein (1996).

2.4.6. Respiration activity and ethylene production (Paper VII):

In the first years of the study reported in Paper VII, respiration activity (measured as CO_2) and internal ethylene production (IEC) were taken from individual apples by inserting a needle in the calyx end of the fruit (Saltveit, 1982). In 2004 and 2005, fruit were placed in 0.5 L jars at 20 ºC. The jars were sealed for 3-4 h before measurements. Ethylene was quantified by gas chromatography 6850, USA, (four column Agilent 19095P – Q04E 250 º MaxHp Plot Q30m x 530µm x 40µm) and respiration (CO_2) was quantified by gas chromatography Inc. 3700, USA (two column Hayesep Q1/4''x 8" and Molsict 5, 3/8"x3"). Respiration rate and ethylene production in heated and non heated fruit were measured by the same methods. Fruits were picked from four orchards (five fruit each), heated at 30 ºC for 48 h, kept at room temperature, and their respiration rate and ethylene production were measured every third day. Another sample without heating was used as a control for comparison.

2.4.7. Skin wax structure:

Skin of warmed and cold fruit was examined by scanning electronic microscope (SEM), to study the changes in skin wax. The samples chosen for SEM were cv. Aroma, without and with heat treatment for 24 or 48 h. Equatorial peels of 4-5 mm^2 from either the sun (red) or shade (yellow) side of the fruit were freshly mounted on double-sided tape on specimen stubs. The samples were immediately studied in a scanning electron microscope (LEO 435VP, Cambridge, UK) with secondary electron detector at a low voltage of 2 kV.

2.4.8. Soil and fruit mineral content:

Mineral content (N, K, Ca, and Mg) was estimated by analysing two fruits/tree or 20 leaves/tree. The analyses were performed by AnalyCen centre, Kristianstad, Sweden, (using NMKL6 and HNO_3-ICP Kjeldahl SS-ISO 11 261 methods (www.analycen.com)).

2.5. Statistical analyses

All parts of this study were conducted at Kivik research station in southern Sweden. The apple (*Malus domestica* Borkh) cultivars Aroma, Cox's Orange Pippin, Ingrid Marie and Katja were used. Orchard spacing was 2 m within rows and 4 m between rows, density 1250 trees/ha. All trees were pruned, fertilised, sprayed and irrigated as recommended for commercial orchards, except for experiments aimed at investigating influences of any of the above mentioned parameters. All experiment parts were replicated 3-4 times, over a minimum of 2 years and a maximum of 10 years. The results were expressed as the mean ± standard deviation (SD), and analysed with MS Excel (Microsoft Inc., USA, and Sass). Data were also analysed by analysis of variance (ANOVA) with the same programme.

3. Results and Discussion

3.1. Bruising

Bruise occurrence increased with increasing impact energy for all cultivars. Dropping fruits from higher than 5 and 10 cm for sensitive and resistant cultivars, respectively, caused physical damage below the surface and might thereby cause high damage to the cellular membranes (Klein, 1987). Among the four parameters used for estimation of bruising (number, diameter, volume, and weight), bruise weight percentage (BWP) was found to be the most accurate. By the use of linear regression, the effect of increasing impact energy on BWP was found to account for 99% of the variation in the three cultivars investigated (Aroma, Cox's Orange Pippin and Ingrid Marie). The other three methods applied were inaccurate, because the numerical parameter did not show constant changes in bruising due to various applications of impact energy. The diameter parameter was related to fruit size, and the volume parameter demanded a spherical and homogeneous shape of the fruit, which is not always realistic for these cultivars (Paper I).

Cv. Aroma apples had the highest bruise susceptibility among the three cultivars tested in the present study. Cv. Cox's Orange Pippin had higher resistance than cv. Ingrid Marie. Because various apple cultivars have the same polyphonl oxidase activity with the same substrate specificity and pH optimum, and because different cultivars have different phenol content (Trejo-Gonzales & Soto-Valdez, 1991; Imeh & Khokhar, 2002), the variation in the browning susceptibility of investigated cultivars may relate to their endogenous phenolic substrates. Cv. Aroma apples had higher total phenol content than cv. Ingrid Marie (Ericson, 2004). This might be the reason for the lower resistance to bruising caused by impact energy in cv. Aroma compared to cv. Ingrid Marie (Milani & Hamedi, 2005; Valentines *et al*., 2005).

Air pre-cooling decreased bruise susceptibility. A positive relationship was found between cultivar sensitivity to bruising and decrease in bruise susceptibility through air pre-cooling. The bruised area in air pre-cooled cv. Aroma apples was 25% smaller than the bruised area in untreated apples. In cv. Ingrid Marie, bruise area decreased by 15% due to air pre-cooling, whereas cv. Cox's Orange Pippin apples were not affected (Fig. 1, $p<0.05$). A vapour gradient between the interstitial air spaces in the fruit cortex and the atmosphere around the fruit increases water loss (Klein, 1987). The current air pre-cooling may enhance this loss, decrease cell turgidity and as a result improve fruit resistance to bruising (Paper II). Heating cv. Aroma fruit at 30 °C for 24 h reduced bruise susceptibility by 25-35% (Paper VI). Post-harvest heating also improved cv. Ingrid Marie resistance to bruising but had no effect on cv. Cox's Orange Pippin apples (Fig. 1, $p<0.05$). Total phenol content of cv. Aroma apples did not show any interaction with post-harvest heating (unpublished data), and thus the effect of this treatment may also be attributed to water loss and turgidity. However, heating has been shown to melt apple skin wax and change its structure (Roy *et al*., 1994). Melted wax clumps (see fig 9, 10, 11) may provide some cushions, partly decreasing the impact energy.

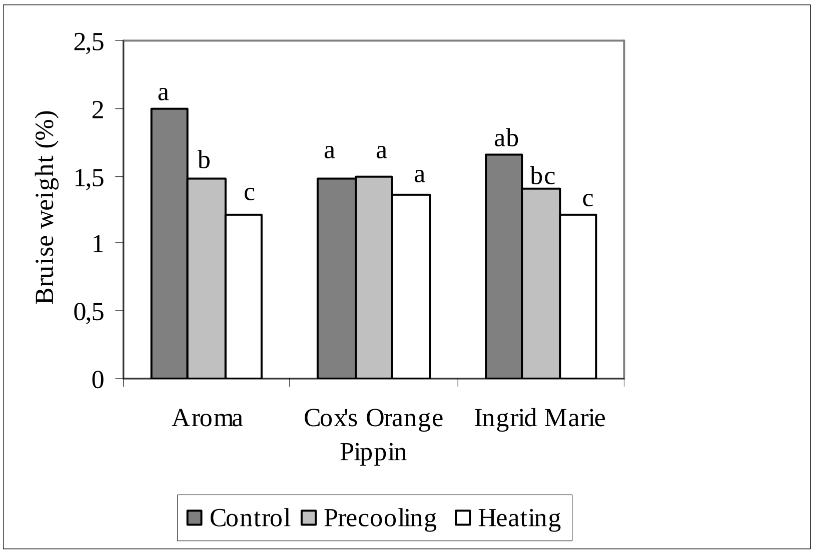


Fig.1. Cultivar response to precooling and heating. Heating (30 °C/24h), precooling cold air current (3-4º C/30h). Different letters within the same column are significantly different at LSD=0.05 n=270 (3 cultivars. 3 factors. 1 drop height (30 cm) 3 replicates. Each replicate consist of 10 fruits).

Cvs. Aroma and Ingrid Marie apples showed a higher bruise susceptibility when fruit were harvested ten days later than the commercial harvesting date. The resistance of cv. Cox's Orange Pippin apples to bruising was not affected (Paper II). Thus, the relationship between harvesting date and bruise susceptibility may be cultivar-dependent and thereby either the suggested correlation (Klein, 1987) or no relationship between harvesting date and bruise occurrence (Antonio *et al*., 2005) can be accepted (Toivonen *et al*., 2003). Total phenol content started to decrease in cv. Aroma apples two weeks after the commercial harvest date, but did not change even after three weeks in cv. Ingrid Marie apples (Ericson, 2004). These results were in contrast to earlier findings reporting that total phenol content, PPO and POX activities decreased during ripening and resulted in low bruising susceptibility (Murata *et al*., 1995; Valentines *et al*., 2005). Late harvested apples had larger size, heavier weight, higher turgidity, more sugar content and less firmness. Higher bruise sensitivity of ripened fruit may be related to these changes.

Improvement of cv. Aroma resistance to bruise occurrence was closely related to several cultural practices. Adjustment of the nitrogen or potassium fertilisation decreased the bruise occurrence by 37% and 29%, respectively, in comparison with excess fertilisation of these two elements (Fig. 2, $p<0.05$). Excess potassium fertilisation showed a higher correlation with fruit bruise sensitivity compared to excess nitrogen fertilisation, because of its stronger correlation with fruit calcium content (Paper IV).

Through covering the orchard floor with aluminium foil, the sensitivity of cv. Aroma apples to bruising was decreased by 37% (Fig. 2) in comparison with conventional mulching. Aluminium foils mulching improved fruit quality and increased red colouration (Paper III). Summer pruning improved fruit colour (Paper IV) and decreased bruise occurrence by 45% compared with winter pruning. No differences between July and August pruning were observed (Fig. 2. $p<0.05$). A significant negative relationship between skin colour and bruise susceptibility of a cultivar was found.

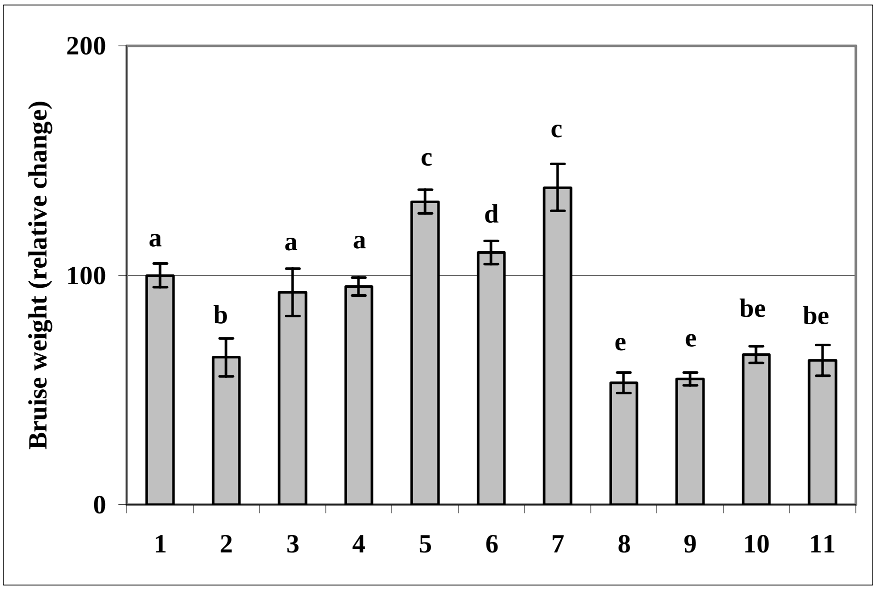


Fig.2. Improve 'Aroma' apples resistance to bruising by adjusting cultural practices. Different letters are significantly different at LSD=0.05. n=990 (11 treatments. 3 years. 1 drop height (30 cm). 30 fruits). Treatments: 1. Classic management (mechanical mulching, winter pruning mid-age tree, and classic fertigation); 2. old tree; 3. young tree; 4. optimum N; 5. excess N; 6. optimum K; 7. excess K; 8. bark mulching; 9. aluminium mulching; 10. July pruning; 11.August pruning.

The sunny side of the cv. Aroma apple was less sensitive than the shade side and red Aroma (Amorosa) apples were more resistant to bruising than Aroma apples (Fig. 3. $p<0.05$). Accumulation of more wax on the red area of the fruit (as seen in Fig. 9A) might be the reason for the increased resistance to bruising through decreasing its sensitivity to impact energy.

ULO storage improved cv. Aroma apple resistance to bruising by 30% in comparison with normal atmosphere storage (Paper VI). This positive effect might be due to delayed softening (Johnston *et al*., 2003) or to a decrease in phenolic acid concentration (Van der Sluis *et al*., 2003) which has been found to be closely related to bruise susceptibility (Valentines *et al*., 2005).

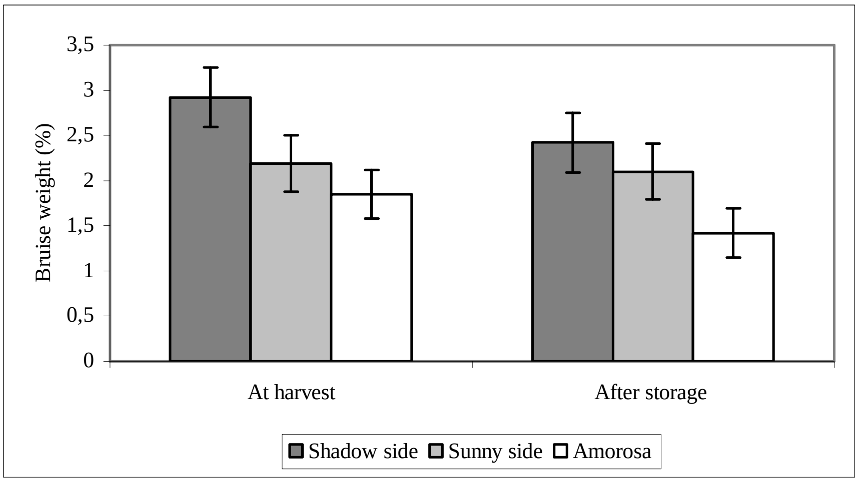


Fig.3. Relationship between skin colour and bruise sensitivity, Drop height 30 cm. Means of three factors, two control dates, three replicates, each sample consist of fifty fruits ± SD, n= 900.

3.2. Pathological diseases and physiological disorders

Pezicula malicorticis and *Colletotrichum gloeosporioides* were the most important causes of storage decay in Swedish apples. The losses due to these fungi were 18.4%. 13.9%, 9.5%, and 5.4% respectively in stored cvs. Aroma, Ingrid Marie, Cox's Orange Pippin and Katja (Fig. 4. $p<0.05$). The most common decay during storage of the four cultivars was bull's eye rot, which is caused by *P. malicorticis* (Rosenberger, 1990). *Penicillium expansum* was also a cause of storage decay in the cultivars investigated. Cvs. Aroma and Ingrid Marie apples generally showed a lower resistance to decay from these two fungi than cvs. Cox Orange Pippin and Katja (Fig. 4. $p<0.05$). Brown rot caused by *Monilia spp.* and grey mould caused by *Botrytis cinerea* were not recorded as a serious problem (data not published). Inoculating fruit with freshly prepared conidial suspension showed that the decay lesions caused by *P. malicorticis* were larger than the decay lesions caused by *P. expansum,* on both cvs. Aroma and Ingrid Marie apples. This, together with the higher percentage of storage decay by *P. malicorticis* and *C. gloeosporioides*, illustrates the higher sensitivity to Gloeosporium rot than to *P. expansum* of these two cultivars. Cv. Cox's Orange Pippin apples showed a more similar resistance to both fungi, through a similar decay lesion size from both fungi (Fig. 5. $p<0.05$).

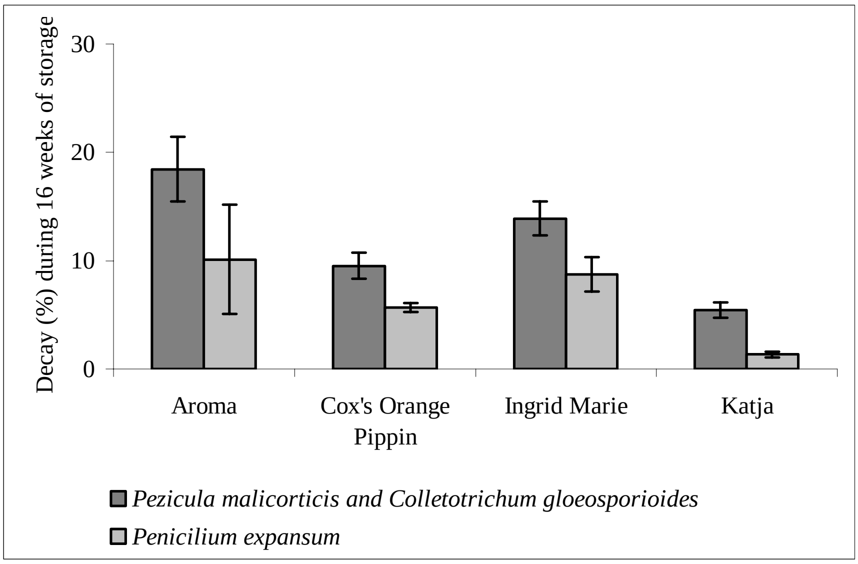


Fig.4. Various cultivars resistance to fungal decay during 16 weeks of storage and 7 days at 20° C. Means of three years, two rot types, 4 cultivars, four orchards. Each sample consisted of 50 fruit. ± SD of n= 96 (2000-2002) average.

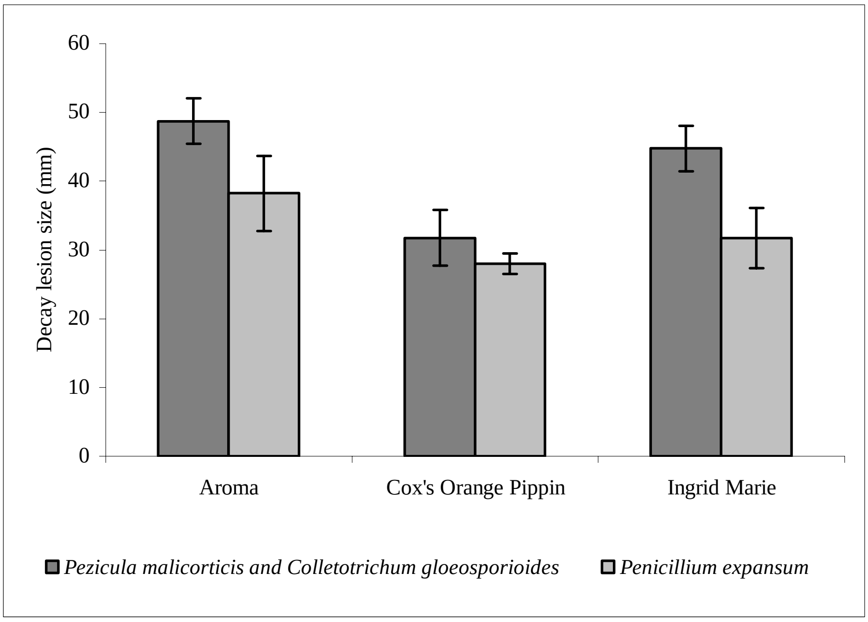
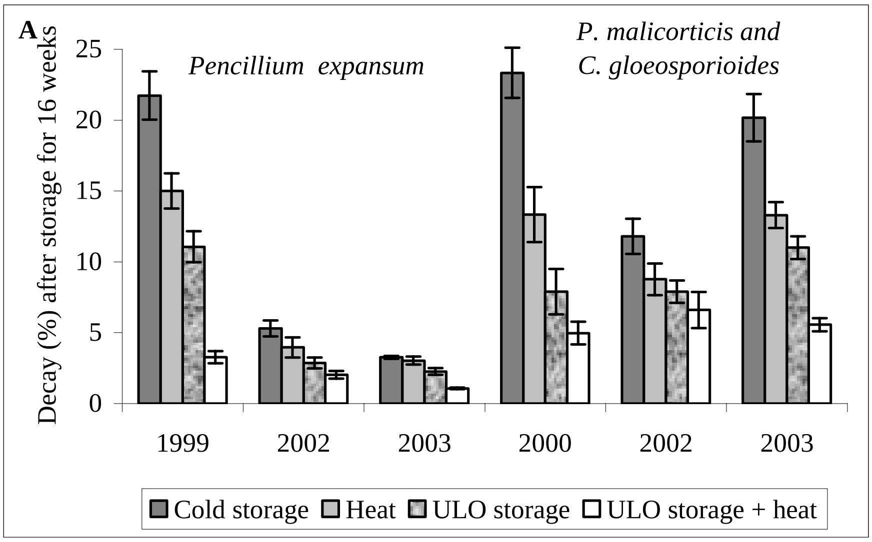
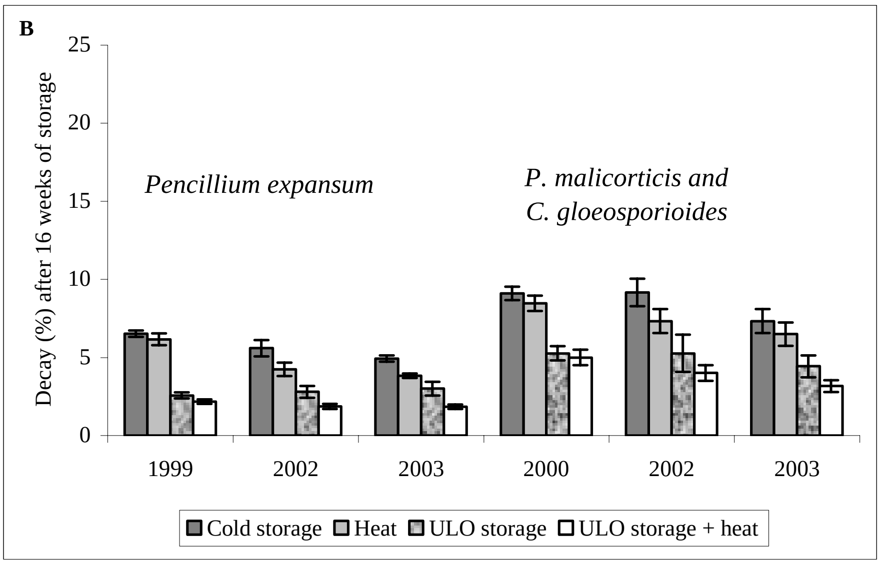


Fig.5. Various cultivars response to inoculation with conidial suspension. Means of three years, two rot types, 3 cultivars, four orchards, ± SD of n= 72 (1999 & 2000 - 2002). Each sample consisted of 50 fruit. Fruit size: Aroma (75-80 g), Cox's Orange Pippin (70-75 g), Ingrid Marie (60-65g).

In comparison with non-treated fruit, heating of cv. Aroma apples at 30ºC for 24 h decreased the decay caused by *P. malicorticis* and *C. gloeosporioides* by 43, 25, and 34%, respectively, for the different seasons (Fig. 6A; $p<0.05$). In two out of three seasons investigated, the heating also decreased blue rot (caused by *P. expansum*) by 31 and 25%. A similar treatment of cv. Cox's Orange Pippin apples showed 20% less decay caused by *P. expansum* during two seasons and 20% less decay caused by *P. malicorticis* and *C. gloeosporioides* during only one season (Fig. 6B; $p<0.05$). In cv. Ingrid Marie too, resistance to fungal rot was improved by heating. Rots caused by *P. expansum* decreased during two seasons by 24 and 17%, and decay caused by *Gloeosporium spp.* decreased by 26-38% in comparison with non-heated fruit (Fig. 6C; $p<0.05$).





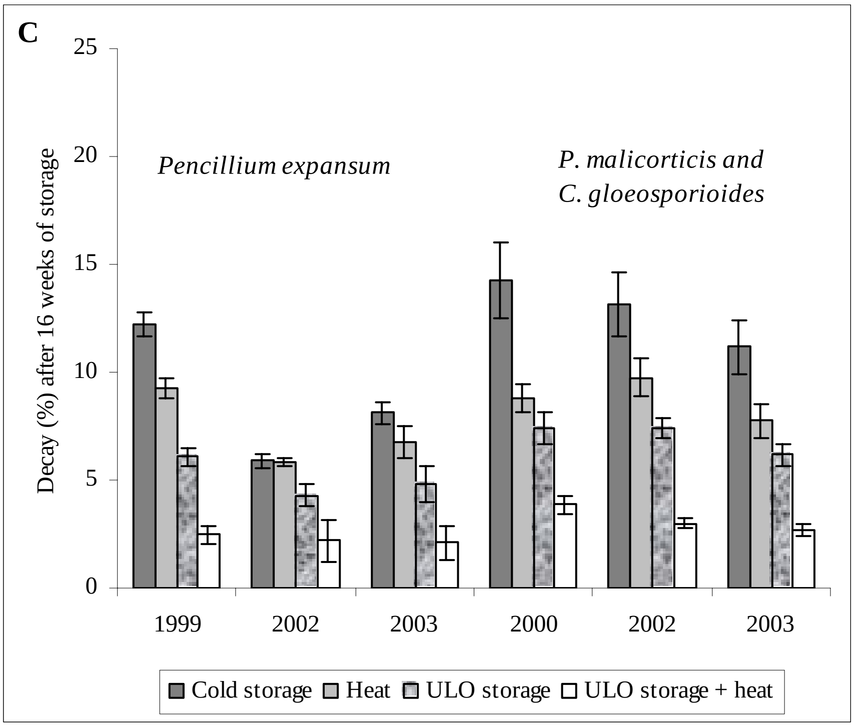
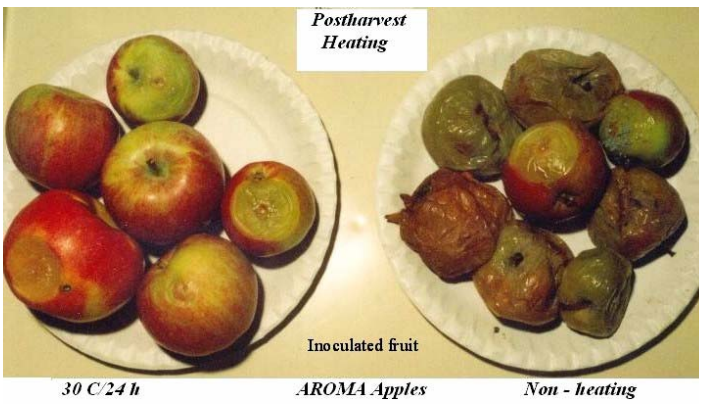


Fig. 6. Effect of ULO storage and heating on fungal decay during 16 weeks of cold storage and 7 days at 20º C. A. Aroma, B. Cox's Orange Pippin, C. Ingrid Marie. Means of two rot types, four treatment, and four orchards. ± SD of n=32. Each sample consisted of 50 fruit.



ULO storage suppressed rots compared to cold storage in all cultivars and during all three seasons investigated (Fig. 6A; 6B; 6C; $p<0.05$). The decrease in *P. expansum* was 49, 46, and 31 % in cv. Aroma, 61, 50, and 39 % in cv. Cox's Orange Pippin and 50, 27, and 41 % in cv. Ingrid Marie (Fig. 6A, 6B, 6C; $p<0.05$). The decay by *P. malicorticis* and *C. gloeosporioides* was reduced by 66, 33 and 45%, respectively per season in cv. Aroma, 42, 43, and 40% in cv. Cox's Orange Pippin and 48, 44, and 39% in cv. Ingrid Marie (Fig. 6A, 6B, 6C; $p<0.05$).

The combination of heat treatment and ULO storage improved resistance to rots even further and thereby resulted in lower decay compared to non-heated, only heated, cold stored and only ULO stored apples (Fig. 6A, 6B, 6C; *p<0.05*).

Several investigations have suggested that heating cannot eliminate spores or kill already existing and growing mycelia (Dettori *et al*., 1996; Lurie *et al*., 1998; Schirra *et al*., 2000). Therefore, the background to the improvement of tissue resistance to pathogens by heating is of interest. This study (Paper VI) showed, similarly to earlier findings (Barkai-Golan & Phillips, 1991; Roebroeck *et al*., 1991; Spadaro *et al*., 2004), that apple response to heat treatment was influenced by cultivar, decay causing agent and temperature. Thus, the decreased storage decay by post-harvest heating suggests that *P. malicorticis, C. gloeosporioides* and *P. expansum* are sensitive to higher temperatures (Porat *et al*., 2000; Trierweiler *et al*., 2003) and the reason might be an inhibitory effect on pathogen growth, or/and a stimulatory effect on certain host-defence responses. The heating might affect the nuclei, cell wall and mitochondria or denature proteins (Barkai-Golan & Phillips, 1991). Fruit defence systems against fungi are achieved by either complex constitutive or non-constitutive interactions, which may be affected by heating (Ben Yehoshua *et al*., 1998).

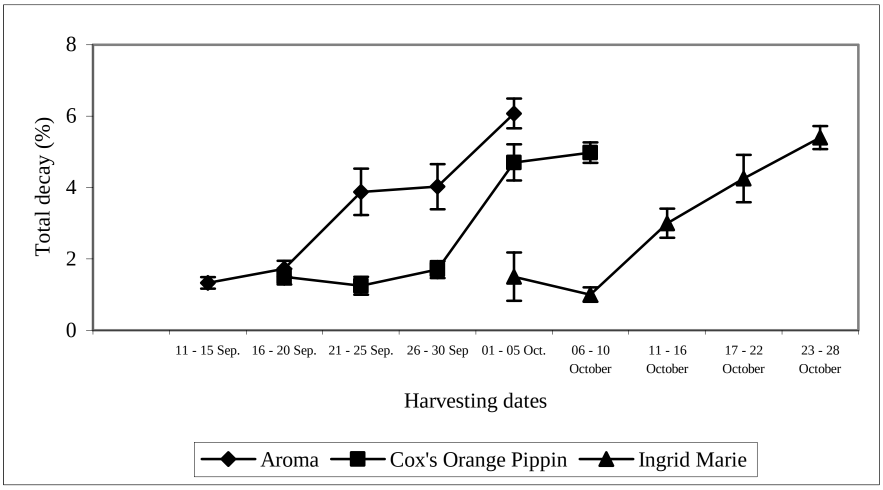
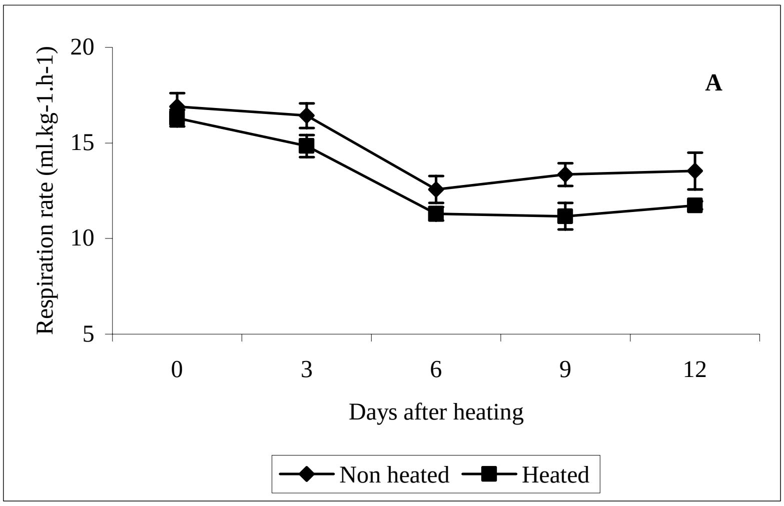


Fig. 7. Relationship between ripening and fungal decay after 16 weeks of cold storage and 7 days at 20° C. Means of ten years, 3 cultivars, nine dates, and four orchards, ± SD of n=1080, (1993 - 2004). Each sample consisted of 50 fruit.

Apple susceptibility to pathogen diseases increased with advanced ripening (Paper VI, Fig. 7 *p<0.05*) as a result of physiological changes that enable pathogens to develop in the fruit (Eckert & Ogawa, 1988). In comparison with non-heated cv. Aroma apples, which showed stable respiration rate after three days of storage at 18 °C, heated cv. Aroma apples started to show a lower respiration rate after the same time of storage (Fig. 8A *p<0.05*).



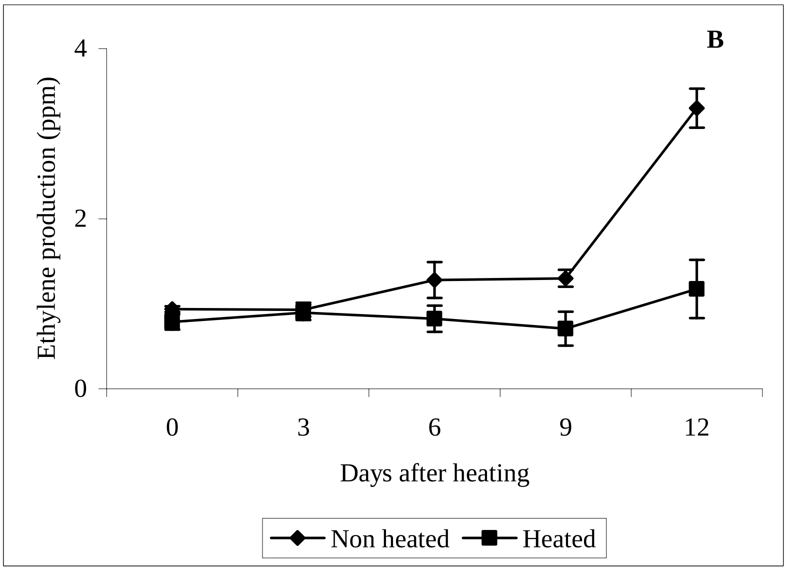


Fig. 8. Effects of post-harvest heating o A) respiration rate B) ethylene production in 'Aroma' apples. Means of five dates, two treatments and four orchards, ± SD of n=40, each sample consisted of 5 fruit.

Ethylene production increased after 6 days of storage in non-heated apples, while it was fairly constant in heated apples (Fig 8B; *$p<0.05$*). Pervious investigations have reported that heating decreases respiration rate (Janisiewicz *et al*., 2003), ethylene production (Saftner *et al*., 2003), or both of these (Conway *et al*., 2004), and may inhibit the synthesis of cell wall hydrolytic enzymes (Lurie, 1998), resulting in delayed ripening and more resistance to storage decay.

Since fungal spores and latent infections are found either on the surface or in the few cells layers under the peel of the fruit (Lurie, 1998; Porat *et al*., 2000), any physiological or structural changes in this area can lead to elimination and/or reduction of pathogen growth (Schirra *et al*., 2000). Heat treatment caused important changes in epicuticular wax. The wax layer on cv. Aroma apples without heat treatment appeared different on various sides of the fruit. The sunny side usually had clumps in the wax layer, whereas on the shade side the wax most often had nail-like crystals (Fig. 9). The wax layer had clearly changed after 30 °C heat treatment for 24h, when wax clumps had started to fuse together to a more continuous layer (Fig. 10).

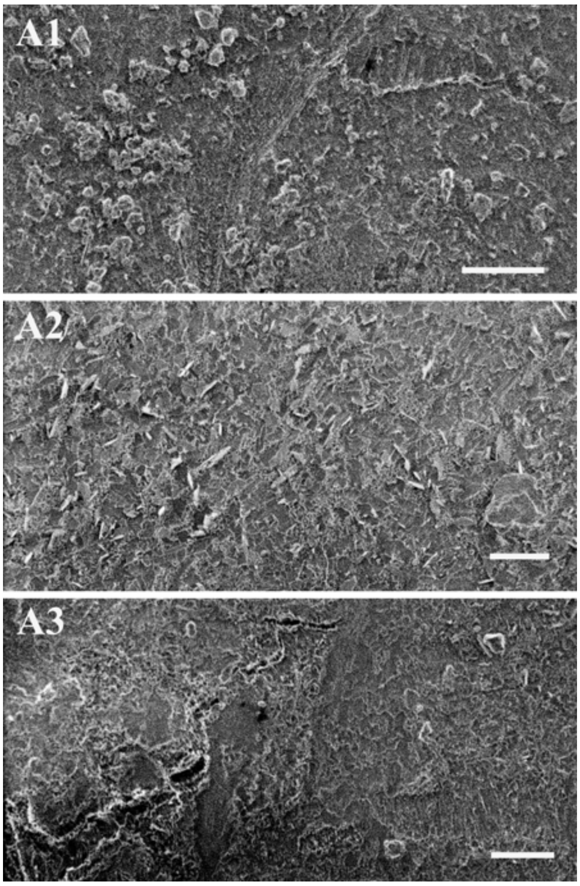
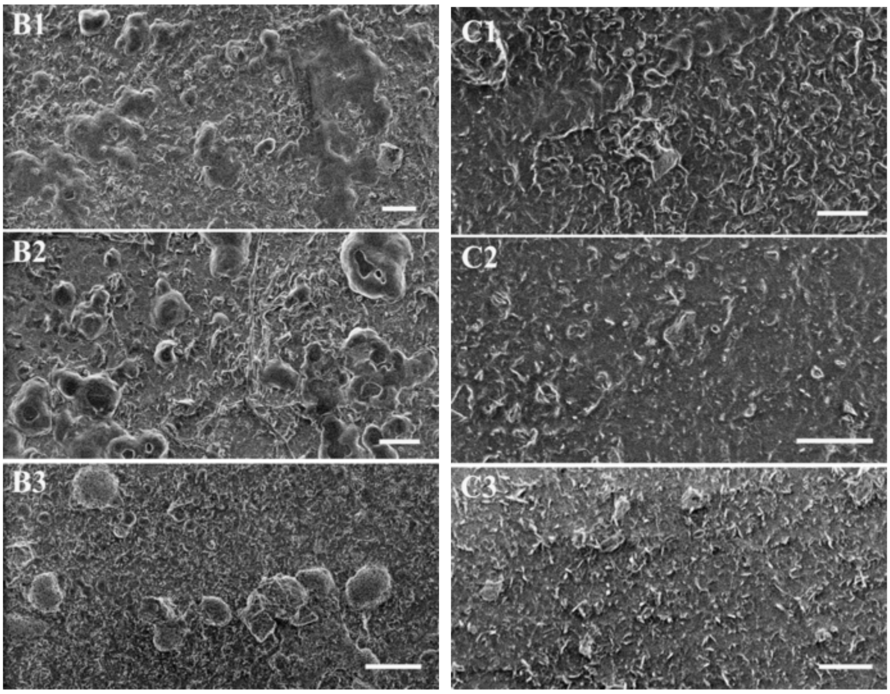


Fig. 9. The surface wax layer in control Aroma apples without heat treatment. A1) Wax clumps on the sun side of the apple. A2) Nail-like wax crystals on the shadow side. A3) A crack on the wax layer. Scale bars 5 µm.



(B). *Fig. 10. The surface wax layer on Aroma after 24 h heat treatment. B1. Wax clumps had started to fuse together. B2. Fungal hyphae captured in the melted wax. B3. On the shadow side, the wax layer was less influenced by the heat treatment. Scale bars 5 µm.*

(C) *Fig. 11. The surface wax layer on Aroma after 48 h heat treatment. C1-C2) The wax clumps had started to fuse to a more even layer. C3) On the shadow side, the wax layers were still less influenced by the heat treatment. Scale bars 5 µm.*

Occasionally, remains of fungal hyphae were seen captured in the wax. After heat treatment for 48 h, the wax clumps were less visible and the wax layer was more even (Fig. 11). However, there was variation in the degree of wax fusion even within the same fruit. The nail-like wax crystals held their form longer than the wax clumps. Heat treatment may stimulate an increase in wax synthesis and its recrystallization. When wax is melted by heating, it might fill micro wounds and also cover germinated spores, conidia and hyphae, and thus hinder inoculation (Figs. 10 and 11), (Roy *et al*., 1994; Schirra *et al*., 1999). However, these suggested mechanisms of the heat effect, including the changes in wax and delaying of ripening, do not exclude the possibility that there might also be other probable effects of heating, resulting in an accumulation of compounds from the antifungal defence system such as lignin and chitinases (Ismail & Brown, 1975; Rodov *et al*., 1997).

The growth of the two fungi was inhibited by exposure of inoculated cv. Aroma apples to vinegar vapour. The lesion area became both smaller and drier. The inhibitory effect of acetic acid on fungal infection might be due to its low pH. Vinegar can also penetrate the microbial cell to exert its toxic effect (Sholberg & Gaunce, 1995; Sholberg *et al*., 2000). Unfortunately, dipping of apples in liquid vinegar or exposing them to vinegar vapour caused black lines on the fruit skin and the treatment sometimes also resulted in a fermented taste. Each black line contained a 2-3 mm deep layer of collapsed cells below the peel (Table 4).

Table 4. Influence of vinegar vapour on decay of 'Aroma' apples which were inoculated by Penicillium expansum (P. e.) and Pezicula malicorticis (P.m.)(2001 - 2003 average). Different letters within the same column are significantly different at LSD=0.05.

Treatment	**Decay (%)**		**Lesion area (mm)**		**Fruit with black lines (%)**		**Fermented taste, 1= very low, 5= very high.**	
	P. e.	P. m.	P. e.	P. m.	P. e.	P. m.	P. e.	P. m.
Control	56.2 a	69.6 a	24.3 a	48.1 a	0.0 b	1.0 b	0.0 b	0.5 b
Vinegar	15.0 b	46.6 b	5.6 b	33.6 a	42.0 a	51.0 a	2.7 a	2.4 a

Clear relationships were found between orchard management and fruit resistance to decay caused by Gloeosporium spp. (Papers III – V). Through comparisons with classical cultural practices, it was found that pruning trees in July or covering the ground of cv. Aroma orchards with aluminium foil were the most effective factors with regard to improvement of fruit resistance to pathogens (Fig. 12; $p<0.05$). Bark mulching and August pruning also decreased rot occurrence by 60 and 44%, respectively, in comparison with the classic management practices (Fig. 12; $p<0.05$). Excess nitrogen fertilisation resulted in higher decay, while optimum N reduced decay by 37% (Fig. 12; $p<0.05$). Excess potassium fertilisation increased storage decay. However, not even optimisation of the K amount led to a significant decrease in storage decay. Fruits from young trees had the lowest resistance to the pathogens (Fig. 12; $p<0.05$).

Decay occurrence in cv. Katja apples could also be decreased by adjusting the cultural practices. Bark mulching improved the resistance to pathogen rot of this cultivar (Table 5; $p<0.05$). Partial thinning and radical pruning did not significantly influence the decay occurrence compared to the control in cv. Katja apples. However, a multi-practices management model resulted in highly improved effects on fruit resistance to pathogen decay (Paper V). Delaying fruit picking for two weeks after optimum harvest date resulted in 200-300% higher fruit losses due to fungus decay for cvs. Aroma, Cox's Orange Pippin and Ingrid Marie. ULO storage decreased decay occurrence by 50% in the late picked fruit in comparison with cold storage (Paper VII).

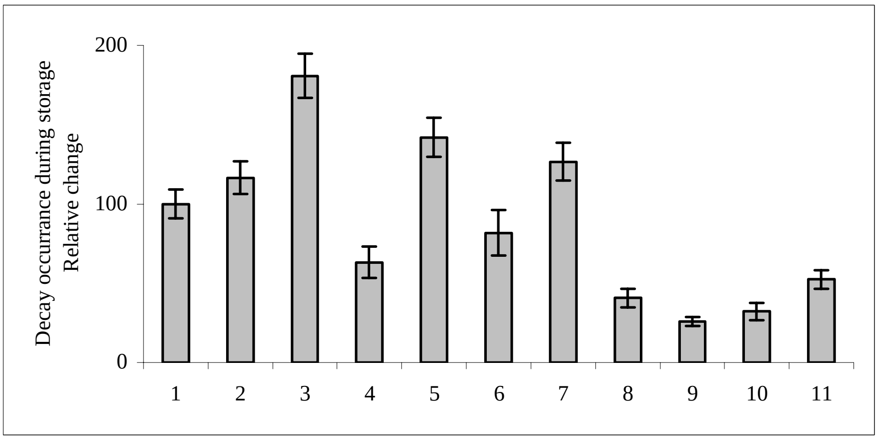


Fig.12. Relationships between cultural practices and decay occurrence during storage of 'Aroma' apples. Means of four years, 11 models, and four orchards, ± SD of n=176. Each sample consisted of 50 fruit. 1. Classic management; 2. old tree; 3. young tree; 4. optimum N; 5. excess N; 6. optimum K; 7. excess K; 8. bark mulching; 9. aluminium mulching; 10. July pruning; 11. August pruning.

Table 5. Comparison between classic model and suggested orchard management models considering yield and storage decay of 'Katja' apples (2000-2003 average). Different letters within the same column are significantly different at LSD=0.05.

Models	**Yield, *relative change***		**Decay, *relative change***	
Classic management	100	e	100	a
Radical pruning	86	f	108	a
Bark mulching	106	e	69	c
Partial thinning	78	g	89	ab
Excess nitrogen fertigation	116	cd	108	a
Bark + excess N	123	bc	86	b
Radical pruning + bark	110	de	45	d
Bark + partial thinning	113	d	51	d
Radical pruning + excess N	103	e	111	a
Excess N + partial thinning	110	d	70	c
Radical pruning + partial thinning	85	f	47	d
Radical pruning + excess N + partial thinning	118	c	76	bc
Radical pruning + bark + excess N	128	b	70	c
Bark + excess N + partial thinning	123	bc	51	d
Radical pruning + bark + partial thinning	121	c	28	e
Radical pruning + bark + excess N + partial thinning	136	a	47	d

Soft scald and internal breakdown were the most important disorders observed during storage of cvs. Aroma, Cox’s Orange Pippin and Ingrid Marie, whereas cv. Katja apples did not suffer from soft scald. Cvs. Aroma and Ingrid Marie showed similar sensitivity to soft scald, which is caused by late harvesting and low storage temperature (Ferguson *et al*., 1998). Cv. Cox’s Orange Pippin suffered mainly from internal breakdown and the occurrence of soft scald was low. However, cv. Ingrid Marie was more sensitive to senescent breakdown than cv. Aroma. ULO storage decreased both of these disorders (Table 6; $p<0.05$).

Poor cropping, large fruit, high nitrogen and low fruit Ca content were correlated with lower apple resistance to pathological and physiological disorders (Robbie & Atkinson, 1994). All practices that achieve a good mineral balance with a better Ca content in the fruit, but also those increasing light interception, enhancing the photosynthesis process and adjusting the competition between fruiting and vigorous growth improve fruit resistance to disorders and decay, and thereby result in good storage potential (Platon & Zagrai, 1997; Wünsche & Lakso, 2000; Veberic *et al*., 2002; Lauri *et al*., 2004).

Table 6. Physiological disorders during storage of four apple cultivars (NA, 2°C + 90% RH. ULO, 2.5% O_2 + 2.5% CO_2 + 2°C). Means (percent of rotten apples) followed by different letters within the same column and year, are significantly different at LSD=0.05.

Disorders	Year	Storage method	Aroma	Cox’s Orange Pippin	Ingrid Marie	Katja
Soft scald	2004	NA storage	6.0 a	4.0 b	6.0 bc	0.0 c
		ULO storage	2.0 bc	0.0 c	4.0 c	No fruits
	2005	NA storage	8.0 a	0.0 c	12.0 a	0.0 c
		ULO storage	3.0 b	0.0 c	6.0 bc	No fruits
Internal break-down	2004	NA storage	6.0 a	9.0 a	7.0 b	6.0 b
		ULO storage	0.0 c	0.0 c	6.0 bc	No fruits
	2005	NA storage	3.0 b	0.0 c	6.0 bc	9.0 a
		ULO storage	0.0 c	0.0 c	4.0 c	No fruits

Therefore, low N, high Ca, low K and high P in the apple can decrease the incidence of storage disorders (Papers IV and V). Internal breakdown and storage decay could be avoided or decreased by increasing fruit Ca content (Ferguson *et al*., 1999). The present study, like earlier investigations (Deckers & Missotten, 1993; Lang & Volz, 1993; Volz *et al*., 1994; Baugher *et al*., 1996; Ferguson *et al*., 1999; Wójcik *et al*., 2001) showed that all treatments increasing Ca movement to developed fruit, such as adjustment of crop load by thinning and pruning, optimisation of N fertigation and K fertilisation, played a visible role in the efforts to develop apple storability. Late picked apples were more prone to develop internal breakdown.

3.3. Fruit yield and quality

3.3.1. Yield

The most essential desire of an apple grower is to produce a maximum yield of high quality fruit at a minimum cost. The results of the present investigations show that different orchard management practices can lead to the realisation of this desire at various levels. Two of the ground cover materials studied, aluminium foil and bark, increased cv. Aroma tree yield by 35% and 26%, respectively, in comparison with the conventional mulching methods, herbicides or mechanical (Paper III, Fig. 13, $p<0.05$). The bark mulch affected the cv. Katja tree yield to a lower degree, although increasing the yield by 7% in comparison with the use of herbicides (Paper V). The estimation of the soil nutrient content in each development phase could be valuable in order to reach the optimum tree nutrition, resulting in higher yield, good quality and less physiological disorders and pathological decay (Paper IV). Such optimum nitrogen fertigation, applied according to monthly soil analysis and fruit growth period, increased cv. Aroma tree yield by 40%, while excess nitrogen (25% more than optimum) increased it by only 15% in comparison with non fertigated trees (Paper IV, Fig. 13, $p<0.05$). Excess potassium fertilisation increased cv. Aroma tree yield by 20% in comparison with standard fertigation, whereas other potassium levels did not affect the tree production (Paper IV, Fig. 13, $p<0.05$). The reason might be a K-effect on enhancement of photosynthetic activity (Schreine & Lüdders, 1996; Guzewski *et al*., 1998; Veberic *et al*., 2002). Excess nitrogen fertigation increased cv. Katja tree yield by 10% in comparison with standard fertigation.

Although a combination of bark mulching and excess nitrogen increased cv. Katja apple yield by 23% in comparison with the classic management, It did not improve the effect of each practice alone (Paper V, Table 5, $p<0.05$). Different pruning dates had no effect on cv. Aroma tree production, regardless of the September pruning, which decreased yield by 23% in comparison with winter pruned trees (Paper IV). Radical pruning decreased cv. Katja tree yield by 14% in comparison with winter pruning. The negative effect of pruning on cv. Katja apple yield could be delay by a combination of pruning with bark mulching or excess nitrogen. However, multi-practices models resulted in 21-36% higher cv. Katja tree yield than the classic management model. The more accurate model was a threefold management model (summer pruning, bark mulching and partial thinning) since it caused the best resistance to storage losses (Paper V, Table 5; $p<0.05$).

Early in the season, vegetative growth takes priority over reproductive development (Grappadelli *et al*., 1994). Thus, adjusting competition of carbohydrates between these two processes by reducing shoot length and number of fruit is very important for improvement of fruit size, yield and quality. One of the main purposes of this study was to investigate which factors infer photosynthetic activity to produce fruit with high quality.

Improving cultural practices was a clear solution to optimise fruit size and yield (Papers VI and V). During June and July, when fruit shows a rapid growth, there is a requirement for a high supply of carbohydrates. A reduction in the competition between fruit and shoot growth by summer pruning or/and thinning is a successful method to ensure an adequate supply of carbohydrates for the fruit

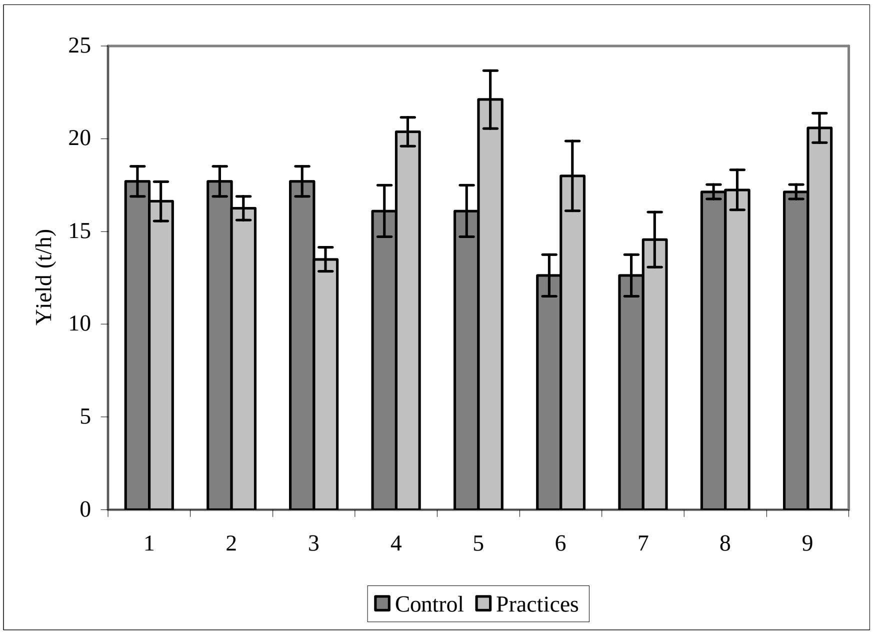


Fig.13. Influence of several cultural practices on 'Aroma' tree yield. Means of four years, 10 models, and four orchards, ± SD of n=160. Each sample consisted of 50 fruit. 1. July pruning; 2. August pruning; 3. September pruning; 4. Bark mulching; 5. Aluminium, mulching; 6. Optimum N; 7. Excess N; 8.Optimum K; 9. Excess K.

(Bepete & Lakso, 1998; Pretorius *et al.*, 2004). The vigorous vegetative growth due to winter pruning or/and excess nitrogen could be inhibited by summer pruning, resulting in larger fruit size and better quality. Cell enlargement which follows cell division (Greybe, 1997) also requires optimal carbon allocation to the fruit. A July or August pruning achieved this purpose and improved fruit quality. However, radical or too late pruning (in September) was shown in this study to decrease yield and quality. The reason for this negative influence on yield and quality might be a reduction in the photosynthetic rate as a result of an imbalance between the sources and sink (Veberic *et al.*, 2002). Light interception is well correlated with tree productivity (Wünsche & Lakso, 2000) and fruit size (Rom, 1990). Summer pruning or aluminium foil mulching, which increases light availability to the fruit, was also found to increase yield of cvs. Katja and Aroma trees. Increases in yield related to ground cover systems might be the result of improvement in soil conditions such as temperature, moisture (Paper III) and nutrient availability (Bramlage *et al.*, 1993). However, some earlier studies have shown contradictory results, *e.g.* no relationship between pruning or mulching and tree productivity (Hampson *et al.*, 2002, Rubauskis *et al.*, 2002).

3.3.2. Firmness and flavour quality (acidity/SSC ratio)

Flesh firmness is one of the important parameters as regards consumer acceptance and eating quality of apples (Wills *et al*., 1980). Cultural practices had different effects on fruit firmness at harvest and during storage. Delaying harvesting for two weeks after the commercial date decreased initial fruit firmness by 20, 15 and 11% in cvs. Aroma, Cox's Orange Pippin and Ingrid Marie apples, respectively (Paper VII). Firmness after storage declined 20-50% faster in late picked apples in comparison with optimal picked fruit (Paper VII). Three cultural practices resulted in firmer cv. Aroma fruit at harvest, namely bark mulching (6% firmer apple), aluminium foil mulching (8%) and summer + winter pruning (10%) (Papers III and IV). Bark mulching increased cv. Katja fruit firmness in comparison with herbicide treatment. The other management models tested showed no improving effect on fruit firmness (Paper V). The rate at which the initial firmness of cv. Aroma apples declined during cold storage was slowed down by 20-25% due to bark or aluminium foil mulching in comparison with the conventional mulching methods (Paper III, Fig. 14, $p<0.05$).

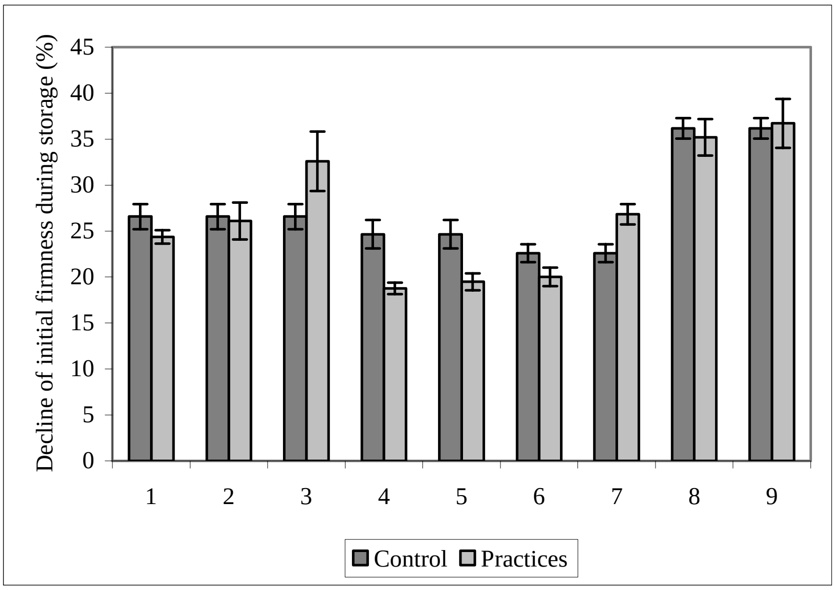


Fig.14. Influence of several cultural practices on the decline of 'Aroma' firmness during storage. Means of four years,10 models, and four orchards, ± SD of n=160. Each sample consisted of 50 fruits. 1. July pruning; 2. August pruning; 3. September pruning; 4. Bark mulching; 5. Aluminium, mulching; 6. Optimum N; 7. Excess N; 8.Optimum K; 9. Excess K.

September pruning and excess nitrogen fertigation enhanced the decline in firmness during storage at similar rates (Paper IV, Fig. 14, $p<0.05$). Post-harvest heating did not affect cvs. Aroma and Cox Orange Pippin fruit firmness (Paper VI, Table 7; $p<0.05$), but increased cv. Ingrid Marie fruit firmness by 12% (Table 7; , $p<0.05$). ULO storage maintained fruit firmness during storage in cvs. Aroma, Cox's Orange Pippin and Ingrid Marie because it caused a slow decomposition of polysaccharides, a change in cell wall materials, and delayed maturity, resulting in a slower decline in firmness (Paper VII). Apples from young trees were softer than apples from older trees and their firmness declined faster during storage (Paper IV).

Each cultivar might have its own minimum SSC and maximum titratable acidity to reach an acceptable flavour quality (Kader, 1999). Delayed harvest date by two weeks decreased the flavour quality, measured as acidity/SSC, by 35, 28, and 24% in cvs. Aroma, Cox's Orange Pippin and Ingrid Marie apples, respectively (Paper VII). At the end of storage, optimum harvested fruit of the three cultivars had 100% better flavour than late picked fruits (Paper VII). ULO stored cv. Aroma apples showed a 20% improvement in flavour quality compared to NA stored apples, and the flavour was also maintained to a 20% higher degree during the storage. Cv. Cox's Orange Pippin fruit showed 5% higher flavour quality and maintained the flavour quality to a 12% higher degree in ULO storage in comparison with NA storage. ULO storage resulted in cv. Ingrid Marie fruit with higher flavour quality that declined more slowly than NA-stored apples (Paper VII). No relationship was found between post-harvest heating and flavour quality of apples, either at harvest or during storage (Table 7; $p<0.05$).

Table 7. Effect of postharvest heating on quality of three apple cultivars during storage (2000-2002 average). Means followed by different letters within the same column are significantly different at LSD=0.05.

Parameter	**Treatment**	**'Aroma'**	**'Cox's Orange Pippin'**	**'Ingrid Marie'**
Firmness (N)	Heated fruit	44.6 a	52.7 a	60.9 a
	Non-heated fruit	44.1 a	52.5 a	54.2 b
Acidity/SSC (%)	Heated fruit	4.7 a	4.8 a	5.6 a
	Non-heated fruit	4.9 a	5.0 a	5.5 a

Cv. Aroma fruit from young trees showed 35% less flavour quality than fruits from older trees. The flavour of fruit from young trees decreased by 56% during storage, whereas the flavour of fruit from old trees only decreased by 40% (Paper IV). Ground cover material systems did not show any effect on cvs. Aroma or Katja apple flavour quality (Papers III and V). During storage, aluminium foil and bark mulching decreased the decline in flavour quality in cv. Aroma apples (Fig. 15, $p<0.05$), while bark mulching did not affect the flavour quality of stored cv. Katja apples (Paper V). Summer pruning improved cv. Aroma fruit flavour quality, irrespective of pruning date (Paper IV). July pruning maintained flavour quality more than August and September pruning (Fig. 15, $p<0.05$). Optimum levels of nitrogen fertigation and potassium fertilisation did not affect cv. Aroma fruit flavour quality at harvest (Paper IV), but they decreased its declination during storage, whereas excess nitrogen or potassium did not show any significant effect (Fig. 15, $p<0.05$). A threefold management model, comprising bark mulching, radical pruning and thinning, improved flavour quality of cv. Katja apples at harvest and the decline in the flavour quality also decreased during storage (Paper V).

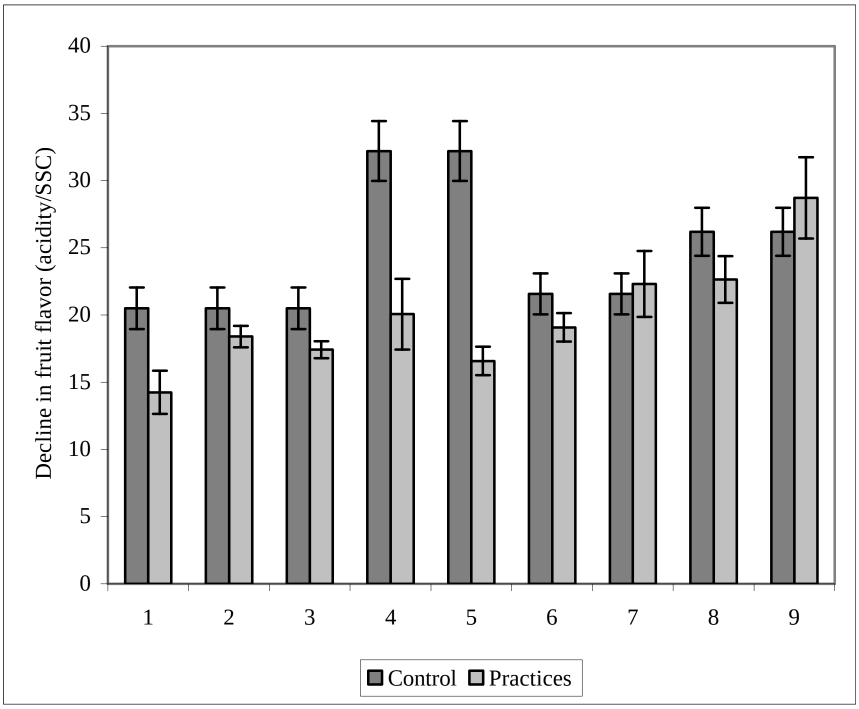


Fig.15. Influence of several cultural practices on the decline of 'Aroma' flavour during storage. Means of four years,10 models, and four orchards, ± SD of n=160. Each sample consisted of 50 fruits. (1. July pruning; 2. August pruning; 3. September pruning; 4. Bark mulching; 5. Aluminium, mulching; 6. Optimum N; 7. Excess N; 8.Optimum K; 9. Excess K.

Firmness decreases during ripening due to solubilisation of middle lamellae, and reduction in galactose residues and water-insoluble pectin (Ben-Arie & Kislev, 1979; Bartley & Knee, 1982). Determination of optimum harvesting date not only affected resistance to disorders, but also had a great effect on fruit quality at harvest and after storage (Watkins *et al*., 1993b; Jobling & McGlasson, 1995). Delayed harvesting date decreases firmness and flavour quality, which is normally highly correlated with ethylene production (Tu *et al*., 1997; Johnston *et al*., 2002). Starch pattern index, which has been widely used as a maturity index in Sweden, is known to be a poor indicator since some internal biochemical changes (*e.g*. in amylopectin) occur during ripening, resulting in poorer staining with iodine in more mature fruit (Watkins *et al*., 1993; Fan *et al*., 1995). Starch degradation pattern also varies according to growing condition of each cultivar (Watkins *et al*., 1982), climate and fruit position in the tree (Brookfield *et al*., 1997). Relationships between ethylene production and optimum harvest date can be poor because it is greatly affected by growing region, pre-harvest conditions, season and nutrition (Watkins *et al*., 2005). The results from the present study showed that there was a period of fruit development, distinguished by very slow changes in the ripening index parameters (decrease in firmness, starch and acidity, increase in SSC). This period separated two other developmental phases when the changes in the same parameters took place at higher rates. To get more an accurate picking date, and ultimately good quality and storability, fruits should be picked when most of these parameters change very slowly at the same time.

Maintenance of firmness in cv. Ingrid Marie through postharvest heating might be due to inhibition of the synthesis of cell wall hydrolytic enzymes, resulting in lower amounts of water-soluble pectin (Klein *et al*., 1990; Ben-Shalom *et al*., 1996; Sozzi *et al*., 1996; Abbott *et al*., 2000, Conway *et al*., 2004).

The decreased rate of decline in the two quality parameters mentioned by ULO storage might be due to a delayed ripening by decreased respiration and ethylene production in the ULO chamber, which caused a slow activity of cell wall degradation enzymes, a slow decomposition of polysaccharides, and a low loss in acidity and biosynthesis of flavour volatiles (Johnson & Colgan, 2003; Kader, 2003).

The production of good quality fruits containing an optimal chemical composition of compounds such as free sugars, organic acids, minerals and vitamins, and having suitable physical properties of characters such as colour, firmness, flavour, *etc*., depends on the activity of photosynthesis and the use of its products (Yamaki, 1995). Because excessive N fertigation result in larger fruits, with larger cells, lower cell wall materials per unit volume, less tissue strength and thus a higher softening rate (Harker *et al*., 1997), excess N caused faster decline in fruit firmness (De Jager & de Putter, 1999). Although optimum N fertigation resulted in a slower decline in fruit firmness and flavour quality, it did not improve the fruit colouration, which deteriorated further with application of excess nitrogen. High N applications might enhance vigorous growth, decrease light availability within the tree crown, increase fruit N content and reduce fruit Ca content (Tomala, 1999).

The role of Ca in the plant and fruit life has been very well studied. Calcium content influences fruit metabolism by restricting cell division, affects cell permeability and cell resistance to the destructive enzymes of fungi (Al-Ami & Richardson, 1987; Conway *et al*, 1993; Sass, 1993). Supplying trees with high N, K and Mg can greatly decrease fruit and leaf Ca content (Righetti *et al*., 1990). In the present study, excessive N fertilisation increasing the K/Ca ratio by 25% resulted in low storage potential of cv. Katja apples (Paper V). Excessive N fertigation or K fertilisation increased nitrogen content and K/Ca ratio in cv. Aroma fruit, resulting in a rapid decline in firmness and flavour quality (Table 8; $p<0.05$; Paper IV). The reduction in fruit Ca content and/or the increase in K/Ca ratio may lead to an accelerated softening process, which is related to an imbalance between K and Ca concentration and also to a higher gas exchange rate in the apples (Hertog *et al*., 2001). Ca is directly associated with fruit firmness since it is involved in strengthening of plant cell walls (Demarty *et al*., 1984). A better light intensity due to July pruning or aluminium foil mulching has been shown to slow down the decline in firmness during storage (Blanpied *et al*, 1978; Volz *et al*., 1995; Basak, 1999; Paper IV). In the present investigation, a clear relationship was found between excess K fertilisation and fruit acidity and/or SSC. This is in agreement with pervious findings (Mott & Steward, 1972).

Table 8. Relation between nitrogen fertigation and 'Aroma' fruit mineral content (1999-2002). Means followed by different letters within the same column are significantly different at LSD=0.05.

Fertigation N (g/tree/day)	N mg/100g fresh weight	Ca mg/100g fresh weight	K mg/100g fresh weight	Mg mg/100g fresh weight	K/Ca
N_0	36.7 c	2.9 ab	100.0 a	3.8 a	34.5 c
N_1	38.8 b	3.0 a	106.0 ab	4.0 a	35.3 c
N_2	39.4 b	2.7 b	104.8 ab	3.9 a	38.8 b
N_3	42.5 a	2.4 c	107.5 b	4.1 a	44.8 a

3.3.3. Colour

Poor red colouration at fruit maturity or after storage still downgrades Swedish apples on the market, stimulating more investigations to improve the fruit colouration. According to the results of this study, improving red colouration in cv. Katja apples could be achieved by applying a threefold model comprising winter and summer pruning, bark mulching and thinning. A twofold model comprising thinning with either bark mulching or winter and summer pruning also led to an improvement in colouration (Paper V).

Classic management ***Multi-practices models***

Effect on colouration of Katja apples

A clear relationship was found between summer pruning and colour of cv. Aroma apples, since fruit from July or August pruned trees were 20% more coloured (lower h° value) than those from classically pruned trees (Fig. 16, $p<0.05$). Aluminium foil mulching was the most successful practice as regards fruit colour, with an 30% increase in comparison with herbicides or mechanical mulching (Fig. 16, $p<0.05$). Optimum and excess nitrogen fertigation led to a decrease in fruit colour of 14 and 20%, respectively, whereas excess potassium fertilisation improved colour only by 10% (Fig. 16, $p<0.05$). Fruit from young trees were 25-35 % more coloured than fruit from older trees (Paper IV). Delaying harvest by one week after the optimum date improved cvs. Aroma, Cox's Orange Pippin and Ingrid Marie apple colouration by 1, 15 and 20%, respectively, in comparison with optimum picked fruit. Fruit colouration was increased by 15, 5 and 30% in cvs. Aroma, Cox's Orange Pippin and Ingrid Marie, respectively, when fruit were picked two weeks after the optimal picking date. Cvs. Aroma and Cox's Orange Pippin apples, which were picked three weeks late, had 20% more colour than optimal picked fruit, whereas cv. Ingrid Marie apples had 45% more colouration (Paper VII).

The red colour in apples is due to the presence of anthocyanin molecules (Van de Meer et al., 1993). These molecules, which belong to the flavonoids, are associated with plant secondary metabolism and can be affected by several factors such as light quality, light intensity, cold stress and pathogen attacks (Kuhn *et al*., 1984). Red skin colour depends on the quantities of chlorophyll and carotenoids pigments present in the apple skin (Saure, 1990; Lancaster *et al*., 1994). The results of the present study showed that the effect of late picking on skin colour is cultivar-dependent. The cultivar Ingrid Marie was the most skin colour sensitive to late picking, followed by cv. Aroma, while cv. Cox's Orange Pippin was the least sensitive cultivar. Colouration depends on fruit position within the tree, since low light intensity reduces anthocyanin synthesis and carbohydrate accumulation, which are the two main factors limiting colouration. In the present investigations, the most efficient practices to increase fruit colour were aluminium foil mulching and July or August pruning. The main reasons for the correlations between cultivation practices and colouration might be a strong efficient interception of light (Dong *et al*., 1995; Wagenmarkers & Callesen, 1995; Barritt *et al*., 1997) and also a better carbohydrate supply resulting from less competition with vegetative growth.

Fruit from young trees were more coloured, larger, softer and richer in SSC than fruit from older trees. This might be the result of poor fruit set and a shorter effective pollination period, resulting in poor cropping (Abbott, 1984; Robbie & Atkinson, 1994).

4. Conclusions

According to the results of this study, better pre- and post-harvest management models could be suggested to improve the fruit quality and storability of some apple cultivars:

A linear regression was found between the bruise susceptibility of three apple cultivars and the impact energy. Cv. Aroma apples, which had the highest internal phenol content of the cultivars investigated, were also the most sensitive to bruising, followed by those of cv. Ingrid Marie. Air pre-cooling and post-harvest heating decreased bruise susceptibility, perhaps due to enhancement of water loss, reduction in cell turgidity, and melting of skin wax. A significant negative relationship was found between skin colour and bruise susceptibility of a cultivar. Although total phenol content did not show any change, delaying picking of cvs. Aroma and Ingrid Marie apples by ten days enhanced bruise susceptibility.

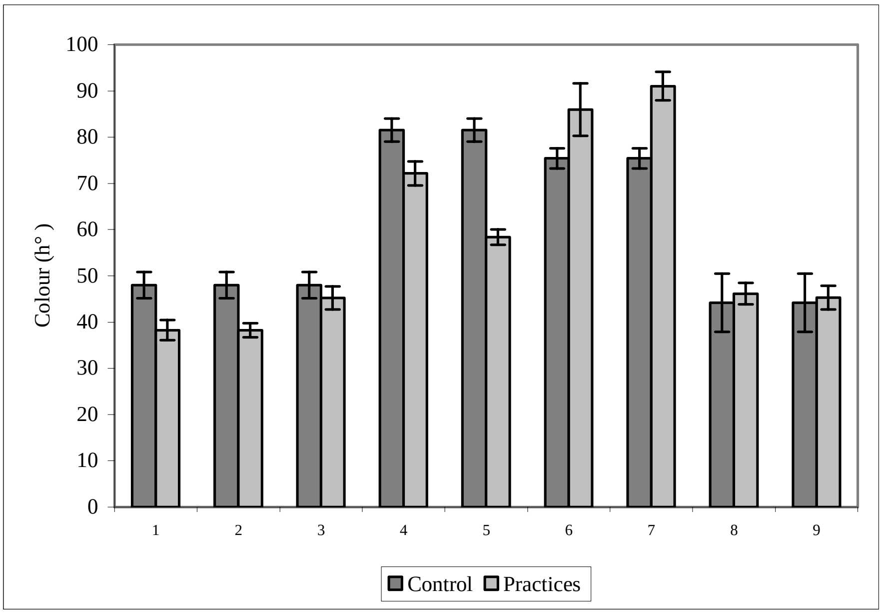


Fig.16. Influence of several cultural practices on the 'Aroma' colour. Means of four years,10 models, and four orchards, ± SD of n=160. Each sample consisted of 50 fruit. 1. July pruning; 2. August pruning; 3. September pruning; 4. Bark mulching; 5. Aluminium, mulching; 6. Optimum N; 7. Excess N; 8.Optimum K; 9. Excess K. Lower h° value = higher red colour.

This enhancement may be caused by softening and high cell turgidity as a result of a decline in firmness and an increase in SSC, respectively. However, total phenol content started to decrease 2 to 3 weeks after the commercial harvest date.

Rot caused by *Pezicula malicorticis* was the most difficult problem during storage of investigated apples, followed by rot caused by *Colletotrichum gloeosporioides* and *Penicillium expansum.* Resistance to fungal rot was cultivar-dependent. Cvs. Aroma and Ingrid Marie were more susceptible to decay than cvs. Cox's Orange Pippin and Katja. Post-harvest heating alone or in combination with ULO storage provided an effective alternative to fungicides against these pathogens. Post-harvest heating inhibits fungal inoculation by fusion of skin wax, covering conidia and hyphae and by filling many of the micro wounds and cracks present. Heating at a high temperature (30-40 ºC) for a short period (24h) was more successful than heating at a low temperature (20-30 ºC) for a longer period (72-96h). Cv. Aroma skin wax consisted of either nail-like crystals or clumps. On the sunny side of the apple, the wax layer was clumpier, whereas on the shade side the nail-like crystals predominated. The clumps did not melt easily. After the heat treatment, the wax layer continued to fuse slowly at room temperature. Vinegar vapour had an inhibitory effect on fungal rot, but the treatment also resulted in black lines on the apple skin and a somewhat fermented taste.

Internal breakdown was the most common physiological disorder affecting cvs. Aroma, Ingrid Marie, Cox's Orange Pippin and Katja. Soft scald was found as a problem only for the first two of these cultivars. By adjusting crop load, picking apples on an accurate date and storing them at a suitable temperature, both of these two disorders could be limited.

Excess nitrogen fertigation was a reason for several production and storage problems such as increased bruise occurrence, pathogen decay and internal breakdown, and reduced yield, colouration and storage potential. Optimum N fertigation could be based on monthly determinations of soil N and on the fruit development phase. Although excess potassium increased yield and colouration, it had negative effects on fruit quality and storability.

Orchard ground cover materials improved fruit quality and storage potential. Aluminium foil and bark mulching increased yield, caused less bruise sensitivity, improved colouration and reduced decay.

July or August pruned apples showed more resistance to bruising and disorders and the quality was improved in comparison with winter pruned apples.

Individual and twofold management models were not sufficient for improvement of the productivity of Katja apple. By using of multi-practices management models unregulated bearing and poor quality fruits were avoided. The most positive effect was the reduction in quality decline during storage.

Fruit from young trees was less resistant to pathogen and had a high bruise sensitivity, showed a better colouration and had a shorter storage life compared to fruit from older trees. The most suitable age for cv. Aroma apple trees was 6-20 years.

No individual maturity index was detected that could be used separately to estimate the optimum harvesting date. A practical method was suggested to be used for determination of optimal picking date. Picked fruit showing a slow change in all or most of their quality parameters (such as firmness, SSC, starch content and acidity) had the highest storage potential.

ULO stored apples showed less bruise sensitivity, less decay and better quality than NA stored apples.

5. Future efforts

Bruising: The main focus for the future should be to investigate the effects of the various management models- suggested as positive models in the present thesis - on the total phenol content and the activity of polyphenol oxidase in some bruise-sensitive cultivars.

Fungal rot: It is important to further refine the heating system by adjustment of the heating period, as well as the method and temperature. Further improvement of the vinegar vapour treatment leading to avoidance of its negative effects on skin and taste, may be another future consideration.

It is very important to investigate the response of other popular cultivars to different conditions of **ULO storage**.

The interaction between **ground cover material systems**, **July pruning** and **nitrogen fertigation** based on soil analysis and fruit development phase should be more investigated, related to other cultivars.

Using **leaf chlorophyll** as an index of leaf N content might lead to replacement of the soil analysis.

Applications of suggested method for determination of the **optimum harvest date,** as presented in this study, have to be evaluated on further cultivars in the area, and investigated at relating to the **consumer acceptability**.

6. Acknowledgements

Now, as I reach the end of the beginning, I remember that I was playing near an apple tree in full blossom by our beautiful house when my mother gave me the first school book fifty years ago. Twenty six years later, I met my wife for the first time in the shade of an apple tree in full blossom! Was the relationship with this tree just chance? However, the image of apple blossom stayed with me when I was forced to leave my mother and my home. Apples have since helped me to create friendships with wonderful people, who always gave me their support and wise advice, and to know many enthusiastic and passionate researchers, who taught me the humanity value of scientific work. First of these friends was the late Nils-Arthur Ericsson, who not only started me on the basics of this study programme, but also introduced me to the Swedish tradition and way of life.

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7. References

Abbott, D. L. 1984. The apple tree: physiology and management. Grower Books, London. In: Robbie, F. A. & Atkinson, C. J. 1994. Wood & tree age as factors influencing the ability of apple flowers to set fruit. *J. Hort. Sci. 69*; 609-623.

Abbott, J.A. 1999. Quality measurement of fruits & vegetables. *Postharvest Biol. Technol. 15*; 207-225.

Abbott, J.A., Klein, J.D., Campbell, T.A., Conway, W.S. & Sams, C.E. 2000. Sensory and firmness measurements of calcium- and heat treated apples. *J. Texture Studies 31*; 109-121.

Ackermann, J., Fischer, M. & Amado, R. 1992. Changes in sugars, acids, and amino acids during ripening and storage of apples (cv. Glockenapfel). *J. Agric. Food Chem. 40*; 1131-1134.

Al-Ami, A.M. & Richardson, D.G. 1987. Relation between calcium concentration, respiration, respiration control ratio and ADP/O ratio of mitochondria isolated from normal and corks potted 'Anjou' pear fruit. *Arab. Gulf J. Res. 5*; 1-11.

Andris, H., Mitcham, B. & Crisosto, C.H. 2002. *Bitter pit in apple. Fruit physiology disorders.* http://postharvest.ucdavis.edu/Produce/Disorders/apple/pdapbit.shtml. Updated June 10, 2002

Antonio Yuri, J., Luis Vasquez, J., Moggia., C. & Diaz, R. 2005. Management of fruit by obtaining low risk of bruising during packaging. *Revista Fruticola 26*; 13-24 (Abs).

Awad, M.A., de Jager, A. & van Westing, L.M. 2000. Flavonoid and chlorogenic acid levels in apple fruit: characterisation of variation. *Scientia Hort. 83*; 249-263.

Awad, M.A. & de Jager, A. 2003. Influences of air and controlled atmosphere storage on the concentration of potentially healthful phenolics in apples & other fruits. *Postharvest Biol. Technol. 27*; 53-58.

Baldwin, E. 2002. Fruit flavour, volatile metabolism and consumer perceptions. In: Knee, M., *Fruit Quality and its Biological Basis.* Ed.; CRC Press: Boca Raton, FL 89-106 pp.

Barkai-Golan, R. & Philips, D.J. 1991. Postharvest heat treatment of fresh fruits and vegetables for decay control. *Plant Dis. 75*; 1085-1089.

Barritt, B.H., Drake, S. R., Konishi, B. S. & Rom, C. R. 1997. Influence of sunlight level and rootstock on apple fruit quality. *Acta Hort. 451*; 569-577.

Bartley, I.M. & Knee, M. 1982. The chemistry of textural changes in fruit during storage. *Food Chem. 9*; 47-58.

Basak, A. 1999. The storage quality of apples after fruitlets thinning. *Acta Hort. 485*; 47-53.

Baugher, T.A., Hogmire, H.W., Biggs, A.R. & Lightner, G.W. 1996. Pack out audits of apples from five orchard management systems. *Hort. Technol. 6*; 34-41.

Ben-Arie, R. & Kislev, N. 1979. Ultra structural changes in the cell wall of ripening apple and pear fruit. *Plant Physiol. 64*; 197-202.

Ben-Arie, R., Levine, A., Sonego, L. & Zutkhi, Y. 1993. Differential effects of CO_2 at low and high O_2 on the storage quality of two apple cultivars. *Acta Hort. 326*; 165-174.

Ben Shalom, N., Hanzon, J., Pinto, R. & Lurie, S. 1996. Cell wall changes & partial prevention of fruit softening in prestorage heat treated 'Anna' apples. *J Sci Food Agric 72*; 231-234.

Ben-Yehoshua, S., Rodov, V. & Peretz, J. 1998. *Constitutive and induced resistance of citrus fruit against pathogens.* In: Johnson, G.I., Highly, E. & Joyce, D.C., Editors 1998. *Disease Resistance in Fruit.* ACIAR Proceeding No. 80, Canberra, Australia, 78-92 pp.

Bepete, M. & Lakso, A. N. 1998. Differential effects of shade on early season fruit and shoot growth rates in 'Empire' apple branches. *HortScience 33*; 823-825.

Bhutani, V.P., Raina, S.S. & Khokhar, U.U. 1995. A note the effect of different floor management systems on cropping & quality of apple. *Haryana J. Hort. Sci. 24*; 35-38.

Blanpied, G.D., Bramlage, W.J., Dewey, D.H., LaBelle, R.L., Massey, L.M., Mattus, G.E., Stiles, W.C. & Watada, A.E. 1978. A standardized method for collecting apple pressure test data. *New York's Food & Life Sciences Bulletin 74*; 1-8.

Borecka, H. & Ceglowska, L. 1973. *Control of bitter rot of apple. Part 1. The effectiveness of fungicides & of spray programmes.* Prace Instytutu Sadownictwa w Skierniewicach 17, 217-222 (Abstr.).

Bound, S. & Daniels, S. 2001. *Optimizing nitrogen rates & application methods to enhance red skin colour development in red Fuji.* http://www.tiar.tas.edu.au/domino/tiarnsf/rdpr13v/PO2. June 2001.

Bramlage, W.J. 1993. Interactions of orchard factors & mineral nutrition on quality of pome fruit. *Acta Hort. 326*; 15-28.

Brookfield, P., Murphy, P., Harker, R. & MacRae, E. 1997. Starch degradation and starch pattern indices, interpretation & relationship to maturity. *Postharvest Biol. Technol. 11*; 23-30.

Brown, S.K. 1992. Genetics of Apple. *Plant Breeding Rev. 9*; 333-366.

Brown, J.H. & Watkins, C.B. 1997. Fruit maturity, carbohydrate and mineral content relationships with water core in 'Fugi' apples. *Postharvest Biol. Technol. 11*; 31-38.

Bruzsewitz, G.H., McCollum, T.G. & Zhang, X. 1991. Impact bruise resistance of peaches. *Amer. Soc. Agric. Eng. 34*; 962-965.

Capek, P., Renard, C.M.G.C. & Thibault, J.F. 1995. Enzymatic degradation of cell walls of apples and characterization of solubilized products. *Intern. J. Biol. Macromolecules. 17*; 337-340.

Cerda, J.J. 1988. *Role of dietary fibre in fruit, vegetable, lipid and mineral metabolism.* In Westwood, M.N., 1993. *Temperate-zone pomology, physiology and culture*, 3d. ed. Timber press, Oregon. 523 pp.

Clifford, M.N. 1997. *Astringency*. In Photochemistry of Fruit and Vegetables; Tomas-Barbera´n, F. A., Robins, R. J., Eds.; Oxford University Press: New York, 87-107 pp.

Conway, W. S., Sams, C. E. & Tobias, R. B. 1993. Reduction in storage decay in apples by postharvest calcium infiltration. *Acta Hort. 326*; 115-121.

Conway, W.S., Sams, C.E., Wang, C.Y. & Abbott, J.A. 1994. Additive effects of postharvest calcium and heat treatment on reducing decay and maintaining quality in apples. *J. Amer. Soc. Hort. Sci. 119*; 49-53.

Conway, W.S., Leverentz, B., Janisiewicz, W.J., Blodgett, A.B., Saftner, R.A. & Camp, M.J. 2004. Integrating heat treatment, biocontrol & sodium bicarbonate to reduce postharvest decay of apple caused by Colletotrichum acutatum & Penecillium expansum. *Postharvest Biol. Technol. 34*; 11-20.

Dahl, C.G. 1929. *Pomologi, I. Äpplen och päron*. Stockholm.

Deckers, T. & Missotten, C. 1993. Influence of training method with or without chemical growth regulation on fruit quality of apples cv. Jonagold, Schone Van Boskoop and Gloster. *Acta Hort. 326*; 39-48.

De Jager, A. & De Putter, H. 1999. Preharvest factors & postharvest quality decline of apples. *Acta Hort. 485*; 103-110.

Demarty, M., Morvan, C. & Thellier, M. 1984. Calcium & the cell wall. *Plant Cell Environ. 7*; 441-448.

Dettori, A., D'hallewin, G., Agabbio, M., Marceddu, S. & Schirra, M. 1996. *SEM. studies on Penicillium italicum – 'Star Ruby' grapefruit interactions as affected by fruit hot water dipping.* Proc. VIII Int. Citrus Congress, 12-17 May 1996, Sun City Resort, South Africa. Vol. 2, 1158-1163 pp.

Dixon, J. & Hewett, E.W. 2000. Factors affecting apple aroma/flavour volatile concentration: a review. *N. Z. J. Crop Hortic. Sci. 28*; 155-173.

Dong, Y.H., Mitra, D., Kootstra, A., Lister, C. & Lancaster, J. 1995. Postharvest stimulation of skin color of Royal Gala apple. *J. Amer. Soc. Hort. Sci. 120*; 95-100.

Ebel, R.C., Proebsting, E.L. & Patterson, M.E. 1993. Regulated deficit irrigation may alter apple maturity, quality and storage life. *HortScience 28*; 141-143.

Eckert, J.W. & Ogawa, J.M. 1988. The chemical control of postharvest diseases: Deciduous fruits, berries, vegetables & root/tuber crops. *Ann. Rev. Phytopathol. 26*; 433-469.

El-Goorani, M.A. & Sommer, N.F. 1981. Fungicides effects of modified atmospheres in fruit and vegetable storage. *Hortic. Rev. 3*; 412-461.

Ericson, F. 2004. Effect of growing district, harvest date & cultivar on the content of total phenols in apples. *SLU*, ISSN, 1403-0993. Sweden.

Ericsson, N.A. 1982. Influence of harvest time on yield, fruit growth and quality in three apple cultivars. *SLU. Rpt. 23, 9-16.* ISSN: 0348-4157.

Ericsson, N-A. 1989. Possibilities for reduction of mechanical damages during distribution of apples. *DGQ, XXIV. Vortragstagung qualitätsaspekte von obst und gemuse,* 126-136.

Erixon, R. 1999. *Äpplen - mat för gudar och människor (Apple is the food of gud & People)*. Örtagård, http://www.medicinsktforum.com/article.asp?id=204.

Fallahi, E., Richardson, D.G., Westwood, M.N. & Chaplin, M.H. 1985. Relationship among mineral nutrition, ethylene, and post-harvest physiology in apples on six rootstocks. *Scientia Hort. 25*; 163-175.

Fan, X., Mattheis, J., Patterson, M. & Fellman, J. 1995. Changes in amylose and total starch content in 'Fuji' apples during maturation. *HortScience 30*; 104-105.

Fan, X., Blankenship, S.M. & Mattheis, J.P. 1999. 1-Methylcyclopropene inhibits apple ripening. *J. Amer. Soc. Hort. Sci. 124*; 690-695.

FAO, 2004. *Food and Agriculture Organization of The United Nations*. http://www.fao.org/

FAO, 2005. *Food and Agriculture Organization of The United Nations*. http://www.fao.org/

Fausett, J.B. & Rom., C.R. 2001. The effects of transitioning a mature high-density orchard from standard herbicide ground cover management system to organic ground – cover management systems. *Arkansas Agricultural Experiment Station. 483*; 33-36.

Faust, M. 1989. *Physiology of temperate zone fruit tree.* New York John Wiley & Sons Inc ISBN: 0471817813, 53-132 pp.

Faust, M. & Shear, C.B. 1972. Fine structure of the fruit surface of three apple cultivar. *J. Amer. Soc. Hort. Sci. 97*; 351-355.

Fellman, J.K., Rudell, D.R., Mattison, D.S. & Mattheis, J.P. 2003. Relationship of harvest maturity to flavour regeneration after CA storage of 'Delicious' apples. *Postharvest Biol. Technol. 27*; 39 -51.

Ferguson, I.B. & Watkins, C.B. 1989. Bitter pit in apple fruit. *Hort. Rev. 11*; 289-355.

Ferguson, I.B. & Watkins, C.B. 1992. Crop load affects mineral concentrations and incidence of bitter pit in `Cox's Orange Pippin' apple fruit. *J. Amer. Soc. Hort. Sci. 117*; 373-376.

Ferguson, I.B. & Boyd, L.M. 2002. Inorganic nutrients & fruit quality. In: Knee, M., *Fruit Quality and its Biological Basis*. Ed.; CRC Press: Boca Raton, FL, 2002; 17-45 pp.

Ferguson, I.B., Volz, R.K., Harker, F. R. & Watkins, C.B. 1995. Regulation of postharvest fruit physiology by calcium. *Acta Hort. 398*; 23-30.

Ferguson, I.B., Snelgar, W., Lay-Yee, M., Watkins, C.B. and Bowen, J.H. 1998. Expression of heat shock protein genes in apple fruit in the field. *Aust. J. Plant Physiol. 25*; 155-163.

Ferguson, I., Volz, R. & Woolf, A. 1999. Preharvest factors affecting physiological disorders of fruit. *Postharvest Biol. Technol. 15*; 255-262.

Ferguson, B., Ben-Yehoshua, S., Mitcham, E.J., McDonald, R.E. & Lurie, S. 2000. Postharvest heat treatments: introduction and workshop summary. *Postharvest Biol. Technol. 21*; 1-6.

Ferree, D.C., Darnell, R.L., Fox, R.D., Brazee, R.D. & Wittmoyer, R.E. 1984. Environmental and nutritional factors associated with scarf skin of 'Rome Beauty' apples. *J. Am. Soc. Hortic. Sci. 109*; 507-513.

Ferree, D.C. & Warrington, I.J. 2003. *Apples. Botany, Production and Uses. Cabi. Publishing*. ISBN, 0 85199 592 6. USA.

Flores, F., Ben Amor, M., Jones, B., Pech, J.C., Bouzayem, M., Latché, A. & Romojaro, F. 2001. The use of ethylene-suppressed lines to assess differential sensitivity to ethylene of the various ripening pathways in cantaloupe melons. *Physiol. Plant. 113*; 128-133.

Funt, R.C., Cameron, E.A. & Banks; N.H. 1999. The effect of apple fruit bruising on total returns. *Research Circular - Ohio Agricultural Research & Development Center* 299; 55-61.

Gheyas, F., Blankenship, S.M., Young, E. & McFeeters, R. 1998. Dietary fibre composition in developing apple fruits. *J. Hort. Sci. Biotechnol. 73*; 631-639.

Ghosh, S.N., Manna, S. & Mathew, B. 2004. Effect of nitrogen and potassium fertilization on custard apple grown under rain fed laterite soils. *Environ. Ecol. 22*; 144-147.

Goffings; G. & Herregods, M. 1994. The influence of the storage conditions on some quality parameters of Jonagold apples. *Acta Hort. 368*; 37-42.

Grajkowski, J., Ochmian, I., Chelpinski, P. & Mikiciuk G. 2004. Evaluation of susceptibility to mechanical damage in several cultivars of apple trees. *Folia Universitatis Agriculturae Stetinensis, Agricultura 93*; 113-117.

Grappadelli, L.C., Lakso, A.N. & Flore, J.A. 1994. Early season pattern of carbohydrate portioning in exposed and shaded apple branches. *J. Amer. Soc. Hort. Sci. 119*; 596-603.

Greybe, E. 1997. The pre- and anthesis factors influencing the fruit size of 'Royal Gala' apples in South Africa. *MSc thesis, University of Pretoria, South Africa.*

Gualandduzzi, S, Neri, F., Brigati, S. & Folchi, A. 2005. Storage of 'Pink Lady' apples quality and bio-pathological aspects. *Acta Hort. 682*; 2077-2084.

Guzewski, W., Bogdanowicz, N., Jadczuk, E., Jakubczyk, H., Lata, B., Sadowski, A. & Whitehead, P. 1998. *Effect of potassium fertilization and irrigation on photosynthesis of 'Katja' apple trees.* Ecological aspects of nutrition and alternatives for herbicides in horticulture. International seminar, Warsaw, Poland, 25-26.

Haffner, K.E. 1993. Storage trail of 'Aroma' apples at the Agricultural University of Norway. *Acta Hort. 326*; 305-313.

Hampson, C.R., Quamme, H.A. & Brownlee, R.T. 2002. Canopy growth, yield, and fruit quality of 'Royal Gala' apple trees grown for eight years in five tree training systems. *HortScience 37*; 627-631.

Harker, F. R., Redgwell, R.J., Hallett, I.C. & Murray, S.H. 1997. Texture of fresh fruit. *Hort. Rev. 20*; 121-224.

Henze, J. 1983. Criteria to determine the quality of apples dependent on harvesting date and storage treatments. *Acta Hort. 138*; 69-75.

Hertog, M.G.L., Hollman, P.C.H., Katan, M.B. & Kromhout, D. 1993. Intake of potentially anticarcinogenic flavonoids and their determinants in adults in The Netherlands. *Nutrition & Cancer 20*; 21-29.

Hertog, M.L.A.T.M., Nicholson, S.E. & Nigel, H.B. 2001. The effect of modified atmosphere on the rate of firmness change in 'Braeburn' apples. *Postharvest Biol. Technol. 23*; 175-184.

Hoehm, E., Gasser, F., Naepflin, B. & Ladner, J. 2005. Consumer expectations and soluble solids, acidity and firmness of plums (*Prunus domestica* 'Cacaks Beauty'). *Acta Hort. 682*; 665-672.

Hofman, P.J. 1998. Production factors influence fruit quality and response to postharvest treatments. In: Coates, L.M. (ed.); Hofman, P. J. (ed.); Johnson, G.I. (ed.), *Disease control and storage life extension in fruit.* 6-18 pp.

Imeh, U. & Khokhar, S. 2002. Distribution of conjugated and free phenols in fruits: antioxidant activity and cultivar variations. *J. Agric. Food. Chem. 50*; 6301-6306.

Ismail, M.A. & Brown, G.E. 1975. Phenolic content during healing of 'Valencia' orange peel under high humidity. *J. Am. Soc. Hort. Sci. 100*; 249-251.

Jadczuk, E., Pietranek, A. & Dziuban, R. 2001. Irrigation and K fertilization effects on the cropping and fruit quality of 'Katja' apple trees on four different rootstocks. *Folia Hort. 13*; 47-60.

Janisiewicz, J.W., Leverentz, B., Conway, S.W., Saftner, R.A., Reed, A.N. & Camp, M.J. 2003. Control of bitter rot and blue mold of apples by integrating heat and antagonist treatments on 1-MCP treated fruit stored under controlled atmosphere conditions. *Postharvest Biol. Technol. 29*; 129-143.

Jarvis, W.R. 1977. Botryotinia and Botrytis species - Taxonomy, physiology and pathogenicity. A guide to the literature. Monograph 14. *Ottawa Research Branch, Canadian Department of Agriculture*: Ottawa, ON, 1977.

Jenks, M.A., Tuttle, J.A., Eigenbrode, S.D. & Feldmann, K.A. 1995. Leaf epicuticular waxes from the Eceriferum mutants in Arabiodopsis. *Plant Physiol. 108*; 369-377.

Jobling, J.J. & McGlasson, W.B. 1995. A comparison of ethylene production maturity and controlled atmosphere storage life of 'Gala', 'Fuji' and 'Lady Williams' apples (Malus domestica, Borkh.). *Postharvest Biol. Technol. 6*; 209-218.

Johnson, D.S. & Colgan, R.J. 2003. Low Ethylene CA Induces Adverse Effect on the Quality of Queen Cox Apples Treated with AVG during Fruit Development. *Acta Hort. 600*; 441-448.

Johnston, J.W., Hewett, E.W. & Hertog, M.L.A.T.M. 2002. Postharvest softening of apple (Malus domestica) fruit: a review. *N.Z.J. Crop Hort. Sci. 30*; 145-160.

Johnston, J.W., Hewett, E.W. & Hertog, M.L.T.A.M. 2003. Softening of 'Cox Orange Pippin' Apples in CA. *Acta Hort. 600*; 521-530.

Jones, A.L. & Sutton, T.B. 1984. *Diseases of Tree Fruits; Michigan State University Cooperative Extension Service:* East Lansing, MI, 25-26 pp.

Juhlin, P. 2003. Växtskydd i ekologisk fruktodling. Rapport, *Juhlins Fruktodlings Rådgivning,* Kristianstad, Sweden.

Kader, A.A. 1999. Fruit maturity, ripening, and quality relationships. *Acta Hort. 485*; 203-207.

Kader, A.A. 2002. Quality parameters of fresh-cut fruit and vegetable products. pp. 11-20. In: Lamikanra, O. (ed.), *Fresh-cut Fruit and Vegetables: Science, Technology and Market.* CRC Press, Boca Raton, USA.

Kader, A.A. 2003. Physiology of CA Treated Produce. *Acta Hort. 600*; 349-354.

Kader, A.A. 2005. Increasing food availability by reducing postharvest losses of fresh produce. *Acta Hort. 682*; 2169-2175.

Kays, S.J. 1999. Preharvest factors affecting appearance. *Postharvest Biol. Technol. 15*; 233-247.

Klein, J.D. 1987. Relationships of harvest date, storage conditions and fruit characteristics to bruise susceptibility of apples. *J. Amer. Soc. Hort. Sci. 112*; 113-118.

Klein, J.D. & Lurie, S. 1989. Prestorage heat treatments as a means of improving poststorage quality of apples. *J. Amer. Soc. Hort. Sci. 115*; 265-269.

Klein, J.D. & Lurie, S. 1992. Heat treatments for improved postharvest quality of horticultural crops. *HortTechnol. 2*; 316-320.

Klein, J.D., Lurie, S. & Ben-Arie, R. 1990. Quality and cell wall components of 'Anna' and 'Granny Smith' apples treated with heat, calcium, and ethylene. *J. Amer. Soc. Hort. Sci. 115*; 954-958.

Klein, J.D., Conway, W.S., Whitaker, B.D. & Sams, C.E. 1997. Botrytis cinerea Decay in apple is inhibited by postharvest heat and calcium treatments. *J. Amer. Soc. Hort. Sci. 122*; 91-94.

Knee, M. 1993. Pome fruits. In: Seymour; G.B., Taylor. J.E., Tucker, G.A., *Biochemistry of fruit ripening.* Eds.; Chapman and Hall: New York, 1993; 325-346 pp.

Koes, R.E., Quattrocchio, F. & Mol, J.N.M. 1994. The flavonoids biosynthetic pathway in plants: function and evolution. *Bioassays 16*; 123-132.

Kovacs, F., Sass, P. & Al-Ariki, K. 1999. Cell wall analyses of different apple cultivars. *Acta Hort. 485*; 219-223.

Kühn, D.N., Chappell, J., Boudet, A. & Halbrock, K. 1984. Induction of phenylalanine ammonia lyase and coumaroyl CoA ligase mRNA in cultured plant cells by UV light or fungal elicitor. *Proc. Nat. Acad. Sci. (USA) 81*; 1102-1106.

Lafer, G. & Brugner, A. 2002. The effect of nutrient content on quality and storage losses of 'Braeburn' apples. *Acta Hort. 594*; 517-520.

Lal Kaushal, B.B. & Sharma, P.C. 1995. Apple handbook of fruit science and technology. In: Salunkhe, D.K., Kadam, S.S.(Eds.), *Production, Composition, Storage and Processing.* Marcel Dekker, New York, 91-122 pp.

Lancaster, J.E., Grant, J.E., Lister, C.E. & Taylor, M. 1994. Skin colour in apples – influence of copigmentation and plastid pigments on shade and darkness of red colour in five genotypes. *J. Amer. Soc. Hort. Sci. 119*; 63-69.

Lang, A. & Volz, R.K. 1993. Leaf area, xylem cycling and Ca status in apples. *Acta Hort. 343*; 56-58.

Lau, O.L. 1998. Effect of growing season, harvest maturity, waxing, low O^2 & elevated CO^2 on flesh browning disorders in 'Braeburn' apples. *Postharvest Biol. Technol. 14*; 131-141.

Lauri, P.E., Willaume, M., Larrive, G. & Lespinasse, J.M. 2004. The concept of centrifugal training in apple aimed at optimizing the relationship between growth and fruiting. *Acta Hort. 636*; 35-42.

Lidster; P.D. & Tung, M.A. 1980. Effect of fruit temperature at time of impact damage and subsequent storage temperature & duration on the development of surface disorders in sweet cherries. *Can. J. Plant Sci. 66*; 555-559.

Link, H. 1993. Influence of pruning on fruit quality and storage potentials of apples. *Acta Hort. 326*; 29-38.

Lister; C.E., Lancaster, J.E. & Sutton, K.H. 1994. Developmental changes in the concentration and composition of flavonoids in skin of a red and a green apple cultivar. *J. Sci. Food. Agric. 64*; 155-161.

López, M.L., Lavilla, T., Recasens, I., Graell, J. & Vendrell, M. 2000. Changes in aroma quality of 'Golden Delicious' apples after storage at different oxygen and carbon dioxide concentrations. *J. Sci. Food Agric. 80*; 311-324.

L´ubomir, H. 2001. *Interactive effect of irrigation and fertilization on the quality of apples*. In: Pro. 9^{th} Intel. Conf. Hort. Lednice – Czech Republic 1, 66-70.

Lurie, S. 1998. Postharvest heat treatments. *Postharvest Biol. Technol. 14*; 257-269.

Lurie, S. & Klein, J.D. 1992. Calcium and heat treatments to improve storability of 'Anna' apples. *HortScience 27*; 36-39.

Lurie, S., Fallik, E., Klein, J.D., Kozar, F. & Kovacs, K. 1998. Postharvest heat treatment of apples to control San Jose scale (Quadraspidiotus perniciosus Comstock) and blue mold (Penicillium expansum Link) and maintain fruit firmness. *J. Amer. Soc. Hort. Sci. 123*; 110-114.

Maini, S.B., Diwan, B., Lal, B.B. & Anand, J.C. 1985. Fruit firmness as a simple index of quality of stored apples. *Indian J. Agr. Sci. 55*; 60-61.

Marsh, K.B., Volz, R.K., Cashmore, W. & Reay, P. 1996. Fruit colour, leaf nitrogen level, and tree vigour in 'Fugi' apples. *New Zeeland J. Crop Hort. Sci. 24*; 393-399.

Maxin, P., Huyskens-Keill, S., Klopp, K. & Ebert, G. 2005. Control of postharvest decay in organic grown apples by hot water treatment. *Acta Hort. 682*; 2153-2157.

McGuire, R.G. 1992. Reporting of objective colour measurements. *HortScience 27*; 1254-1255.

Milani, J. & Hamedi, M. 2005. Susceptability of five apple cultivars to enzymatic browning. *Acta Hort. 682*; 2221-2226.

Mordue, J.E.M. 1998. *Sclerotinia laxa. IMI Descriptions of Fungi and Bacteria* (No. 62): Sheet 619.

Mott, R.L. & Steward, F.C. 1972. Solute accumulation in plant cells. V. An aspect of nutrition and development. *Ann. Bot. 36*; 915-937.

Murata, M., Tsurutani, N., Tomita, M., Homma, S. & Kaneko, K. 1995. Relationship between apple ripening and browning: changes in polyphenol content and polyphenol oxidase. *J. Agric. Food Chem. 43*; 1115-1121.

Näslund, G. 2000. *Äppelbok*. ISBN, 9-630-8788X, Sweden.

Näslund, G. & Sandeberg, I. 2002. *100 älskade äpplen*. Fält and Hässler. ISBN, 91-631-2123-9.

Onions, A.H.S. 1998. *Penicillium expansum. IMI Descriptions of Fungi and Bacteria* (No. 10) : Sheet 97.

Paoli, N. 1997. What does fertigation have to offer? *Obstbau Weinbau 34*; 10-13.

Parr, A.J. & Bolwell, G.P. 2000. Phenols in the plant and in man. The potential for possible nutritional enhancement of the diet by modifying the phenols content or profile. *J. Sci. Food Agri. 80*; 985-1012.

Paull, R.E. 1999. Effect of temperature and relative humidity on fresh commodity quality. *Postharvest Biol. Technol. 15*; 263-277.

Paull, R.E. & Chen, N.J. 2000. Heat treatment & fruit ripening. *Postharvest Biol. Technol. 21*; 21-37.

Peirs, A., Scheerlinck, N., Perez, A.B., Jancsók, P. & Nicolai, B.M. 2002. Uncertainty analysis and modelling of the starch index during apple fruit maturation. *Postharvest Biol. Technol. 26*; 199-207.

Perring, M.A. 1989. Apple fruit quality in relation to fruit chemical composition. *Acta Hort. 258*; 365-372.

Petracek, P.D. & Bukovac, M.J. 1995. Rheological properties of enzymatically isolated tomato fruit cuticle. *Plant Physiol. 109*; 675-679.

Phillips, C.A. 1996. Modified atmosphere packaging and its effects on the microbiological quality and safety of produce. *Int. J. Food Sci. Technol. 31*; 463-479.

Pierson, C.F., Ceponis, M.J. & McColloch, L.P. 1971. *Market Diseases of Apples, Pears, and Quinces.* United States Department of Agriculture Handbook No. 376, 112 pp.

Platon, I. & Zagrai, I. 1997. The influence of training system and pruning time on growth and apple fruiting. *Acta Hort. 451*; 513-518.

Porat, R., Pavoncello, D., Peretz, J., Weiss, B., Daus, A., Cohen, L., Ben-Yehoshua, S., Fallik, E., Droby, S. & Lurie, S. 2000. Induction of resistance to Penicillium digitatum and chilling injury in 'Star Ruby' grapefruit by a short hot water rinse and brushing treatment. *J. Hort. Sci. Biotech. 75*; 428-432.

Pretorius, J.J.B., Wand, S.J.E. & Theron, K.I. 2004. Fruit and shoot growth following combined girdling and thinning of 'Royal Gala' apple trees. *Acta Hort. 636*; 401-407.

Raese, J.T., Drake, S.R. & Roberts, R.G. 1990. *Preharvest calcium treatments reduce storage disorders and improve fruit quality of apples and pears.* In: Proc. 5th Intl. C.A. Res. Conf. 53-61.

Rein, A. 1996. Apple storage disorders (original title in Swedish: Skador på äpplen vid Inlagring). *Swedish Board of Agr. Agro. Info. 3810 Gvarv.*

Righetti, T.L., Wilder, K.I. & Cummings, G.A. 1990. Using plant mineral analysis in orchards. In: Westwood, M.N., *Temperate-Zone Promology: Physiology and culture.* 1993. 523 pp.

Robbie, F.A. & Atkinson, C.J. 1994. Wood and tree age as factors influencing the ability of apple flowers to set fruit. *J. Hort. Sci. 69*; 609-623.

Robinson, J.E., Browne, K.M. & Burton, W.G. 1975. Storage characteristics of some vegetables and soft fruits. *Ann. Appl. Biol. 81*; 399-408.

Rodov, V., Peretz, J., Ben-Yehoshua, S., Agar, T. & D'hallewin, G. 1997. Heat applications as complete or partial substitutes for postharvest fungicide treatments of grapefruit and oroblanco fruits. In: Manicom, B., Editor, 1996 *Proceedings of the International Society of Citriculture 2*, 1153-1157.

Roebroeck, E.J.A., Jansen, M.J.W. & Mes, J.J. 1991. A mathematical model describing the combined effect of exposure time and temperature of hot-water treatments on survival of gladiolus cormels. *Ann. Appl. Biol. 119*; 89-96.

Rom, C.R. 1990. Light distribution in and photosynthesis of apple tree canopies. *Acta Hort.. 279*; 283-290.

Rosenberger, D.A. 1990. Postharvest diseases. p. 53-54. In: A.L. Jones & H.S. Aldwinckle (eds) *Compendium of apple & pear diseases.* APS Press, St. Paul MN.

Roy, S., Conway, W.S., Watada, A.E., Sams, C.E., Erbe, E.F. & Wergin, W.P. 1994. Heat treatment affects epicuticular wax structure and postharvest calcium uptake in 'Golden Delicious' apples. *HortScience 29*; 1056-1058.

Rubauskis, E., Skrivele, M., Dimza, I. & Berlands, V. 2002. The response of apple trees to fertigation and mulch. *Sodininkyste ir Darzininkyste. 21*; 126–133.

Saftner, R.A., Abbott, J.A., Conway, W.S. & Barden, C.L. 2003. Effects of 1-Methylcyclopropene and heat treatments on ripening and postharvest decay in 'Golden Delicious' apples. *J. Amer. Soc. Hort. Sci. 128*; 120-127.

Saltveit, M.E., Jr. 1982. Procedures for extracting and analyzing internal gas samples from plant tissues by gas chromatography. *Hortscience 17*; 878-881.

Saltveit, M. 1984. Effect of temperature on firmness and bruising of Starkrimson Delicious and Golden Delicious apples. *HortScience 19*; 550-551.

Sanz, C. 2005. Postharvest management beyond quality maintenance. *Acta Hort. 682*; 427-435.

Sams, C.E. 1999. Preharvest factors affecting postharvest texture. *Postharvest boil. Technol. 15*; 249-254.

Sass, P. 1993. *Fruit storage.* Arpad Aranyossy (Ed), Mezogazda Kiado, Budapest, Hungary, 41-53. pp. 350.

Saure, M. 1990. External control of anthocyanin formation in apple. *Scientia Hort. 42*; 181-218.

Schirra, M., D'hallewin, G., Inglese, P. & La Mantia, T. 1999. Epicuticular changes and storage potential of cactus pear [Opuntia ficus-indica Miller (L.)] fruit following gibberellic acid preharvest sprays and postharvest heat treatment. *Postharvest Biol. Technol. 17*; 79-88

Schirra, M., D'hallewin, G., Ben-Yehoshua, S. and Fallik, E. 2000. Host-pathogen interactions modulated by heat treatment. *Postharvest Biol. Technol. 21*; 71-85.

Schoorl, D. & Holt, J.E. 1977. The effect of storage time and temperature on the bruising of Jonathan, Delicious and Granny Smith apples. *J. Text. Stud. 8*; 409-416.

Schreine, M. & Lüdders, P. 1996. Gas exchange of apple trees under salinity and various levels of 'K^+ Supply. *Gratenbauwissenschaft*, *61*; 46-49.

Schulz, F.A. 1978. Some physiological and biochemical aspects of the action mechanism of fungal parasites during fruit storage. *Fruits 33*; 15-21.

Sekse, L. 1993. A study of the actual durability of the harvest period of 'Gravenstein' apples. *Acta Hort. 326*; 285-290.

Sharples, R.O. 1980. The influence of orchard nutrition on the storage quality of apples and pears grown in the United Kingdom. In: Atkinson, D., Jackson, J.E., Sharples, R.O., & Waller, W.M. (Eds.), *Mineral Nutrition of Fruit Trees.* Butterworth's, London, 17-28 pp.

Sharples, R. O. 1984. The influence of Preharvest conditions on the quality of stored fruit. *Acta Hort. 157*; 93-104.

Shewfelt, R.L. 1999. What is quality? *Postharvest Biol. Technol. 15*; 197-200.

Shewfelt, R.L. & Purvis, A.C., 1995. Toward a comprehensive model for lipid peroxidation in plant tissue disorders. *HortScience 30*; 213-218.

Shirley, B.W. 1996. Flavonoids biosynthesis: new functions for an old pathway. *Trends Plant Sci. 1*; 377-382.

Sholberg, P.L. & Gaunce, A.P. 1995. Fumigation of fruit with acetic acid to prevent postharvest decay. *HortScience 30*; 1271-1275.

Sholberg, P., Haag, P., Hocking, R. & Bedford, K. 2000. The use of vinegar vapor to reduce postharvest decay of harvested fruit. *HortScience 35*; 898-903.

Smith, R.B., Lougheed, E.C., Franklin, E.W. & McMillan, I. 1979. The starch iodine test for determining stage of maturation in apples. *Can. J. Plant Sci. 59*; 725-735.

Snowdon, A.L. 1990. *A colour atlas postharvest diseases and disorders of fruits and vegetables.* CRC Press, Boca Raton, FL.

Soares, A.G., Trugo, L.C., Botrel, N. & da Silva Souza, L.F. 2005. Reduction of internal browning of pineapple fruit (Ananas Comusus L.) by Preharvest soil application of potassium. *Postharvest Biol. Technol. 35*; 201-207.

Sommer, N.F., Mitchell, F.G., Guillou, R. & Luvisi, D.A. 1960. Fresh fruit and transit injury. *Am. Soc. Hortic. Sci. 76*; 156-162.

Sozzi, G.O., Cascone, O. & Fraschina, A.A. 1996. Effect of a high temperature stress on endo-b-mannanase and a- and b-galactosidase activities during tomato fruit ripening. *Postharvest Biol. Technol. 9*; 49-63.

Spadaro, D., Vola, R., Piano, S. & Gullino, M. 2002. Mechanisms of action and efficacy of four isolates of the yeast Metschnikowia pulcherrima active against postharvest pathogens on apples. *Postharvest Biol. Technol. 24*; 123-134

Spadaro, D., Garibaldi, A. & Gullino, M.L. 2004. Control of Penecillium expansum and Botrytis cinerea on apple combining a biocontrol agent with hot water dipping and acibenzolar-S-mathyl, baking soda, or ethanol application. *Postharvest Biol. Technol. 33*; 141-151.

Stampar, F., Hudina, M., Usenik, V., Sturm, K. & Veber, G. 2002. Experience with foliar nutrition in apple orchard. *Acta Hort. 594*; 547-552.

Staples, R. & Mayer, A. 1995. Putative virulence factors of Botrytis cinerea acting as a wound pathogen, *FEMS Microbiol. Lett. 134*; 1-7.

Streif, J. 1996. Optimum harvest date for different apple cultivars in the 'Bodensee' area. In: de Jager, A., Johnson, D., Hohn, E. (Eds.), COST 94. *The postharvest treatment of fruit & vegetables: Determination & prediction of optimum harvest date of apple & pears.* ECSC-ECEAEC, Brussels, 15-20 pp.

Svensson, H. 2003. *Äpplen i Sverige. (The Apple in Sweden).* Foto: Kent Kastman, Prisma. ISBN, 91-518-4000-6, Sweden.

Tahir, I.I. 2004. Aroma Kvalitet kan förbättras. *Fakta. SLU.* Sweden.

Terlouw, J.C. 2003. Logistics and transport: limiting for the division labour. *Acta Hort. 600*; 43-45.

Toivonen, P.M.A, Gong, Y. & Lau, O.L. 2003. Levels of antioxidant enzymes and lipid soluble antioxidants are associated with susceptibility to internal browning in 'Braeburn' apples. *Acta Hort. 600*; 57-62.

Tomala, K. 1999. Orchard factors affecting fruit storage quality and prediction of harvest date apples. *Acta Hort. 485*; 373-383.

Tomala, K. & Dilley, D.R. 1989. *Calcium content of McIntosh and Spartan is influenced by the number of seeds per fruit.* In: Proc. 5^{th} Intl. C.A. Res. Conf. 53-61.

Tong, C.B.S., Bedford, D.S., Luby, J.J., Beaudry, R.M., Mattheis, J.P., Propsom, F.M., Watkins, C.B. & Weis, S.A. 2003. Location and temperature effects on soft scald in 'Honeycrips' apples. *HortScience 38*; 1153-1155.

Topping, A.J. & Luton, M.T. 1986. Cultivar differences in the bruising of English apples. *J. Amer. Soc. HortScience 61*; 9-13.

Trejo-Gonzales, A. & Soto-Valdez, H. 1991. Partial characterization of polyphenoloxidase extracted from 'Anna' apple. *J. Amer. Soc. Hort. Sci. 116*; 672-675.

Trierweiler, B., Schirmer, H. & Tauscher, B. 2003. Hot water treatment to control Gloesporium disease on apples during long-term storage. *J. applied botany 77*; 156-159.

Tu, K., Waldron, K., Ingham, L., de Barsy, T, & de Baerdemaeker, J. 1997. Effect of picking time and storage conditions on 'Cox's Orange Pippin' apple texture in relation to cell wall changes. *J. Hort. Sci. 72*; 971-980.

Valentines, M.C., Vilaplana, R., Torres, R., Usall, J. & Larrigaudiére, C. 2005. Specific roles of enzymatic browning and lignifications in apple disease resistance. *Postharvest Biol. Technol. 36*; 227-234.

Van der Meer, I.M., Stuitje, A.R. & Mol, J.N.M. 1993. Regulation of general phenylpropanoid and flavonoids gene expression. In: Verma, D.P.S., (Ed.), *Control of Gene Expression*. CRC Press, Boca Raton, FL, 125-155 pp.

Van der Sluis, A.A., Dekker, M., Jongen, W.M.F. & de Jager, A. 2003. Polyphenolic antioxidant in apples. Effect of storage conditions on four cultivars. *Acta Hort. 600*; 533-539.

Vangdal, E. & Hjeltnes, S.H. 2003. Prover med Extenday reflekterande. *Norsk frukt og baer* 6, 10-11. (NOR)

Varro, qtd. In: Westwood, M.N. 1993. *Temperate-Zone Promology: Physiology and culture.* Timber Press, Portland, OR.

Veberic, R., Stampar, F. & Vodnik, D. 2002. Influence of the application of phosphoru and potassium on the photosynthetic in apple trees (*Malus Domestica* Borkh). *Acta Hort. 594*; 165-170.

Velickovic, M. 1992. The effect of training and irrigation on fruit quality and storage life of some important apple cultivars. *Jugoslovensko Vocarstvo 26*; 55-58.

Veraverbeke, E.A., Van Oostveldt, P., Decastro, I.C. & Nicolai, B.M. 2001. Analysis of apple (Malus Domestica Borkh.) wax by means of chromatographic techniques and confocal microscopy. *Acta Hort. 553*; 519-521.

Vincente, A.R., Chaves, A.R., Civello, P.M. & Martinez, G.A. 2003. Effects of Combination of Heat Treatments and Modified Atmosphere on Strawberry Fruit Quality. *Acta Hort. 600*; 197-199.

Volz, R.K., Ferguson, I.B., Hewett, E.W. & Wolley, D.J. 1994. Wood age and leaf area influence fruit size and mineral composition of apple fruit. *J. Hortic. Sci. 69*; 385-395.

Volz, R.K., Palmer, J.W. & Gibbs, H.M. 1995. Within-tree variability in fruit quality and maturity for ‘Royal’ apple. *Acta Hort. 379*; 67-74 1.

Volz, R.K., Tustin, D.S. & Ferguson, I.B. 1996. Pollination effects on fruit mineral composition, seeds and cropping characteristics of “Braeburn” apple trees. *Scientia Hort. 66*; 169-180.

Wagenmakers, P.S. & Callesen, O. 1995. Light distribution in apple orchard systems in relation to production & fruit quality. *J. Hort. Sci. 70*; 935-948.

Warrington, I.J., Stanley, C.J., Julian, J.F., Tustin, D.S., Hirst, P.M., & Cashmore, W. 1995. Pruning strategies for restructuring top-dominant central leader ‘Granny Smith’ apple trees. *N.Z.J. Crop Hort. Sci. 23*; 315-322.

Watkins, C.B. & Rosenberger, D.A. 2002. Cornell Fruit Handling and Storage Newsletter, http://www.hort.cornell.edu/departement/facullty/watkins/extpubs.html. 14 pp.

Watkins, C.B., Reid, M.S., Harman, J.E. & Padfield, C.A.S. 1982. Starch iodine pattern as a maturity index for Granny Smith apples. 2. Differences between districts and relationship to storage disorders and yield. *N.Z.J. Agric. Res. 25*; 587-592.

Watkins, C.B., Brookfield, P.L. & Harker, F.R. 1993a. Development of maturity indices for the ‘Fuji’ apple cultivar in relation to watercore incidence. *Acta Hort. 326*; 267-275.

Watkins, C., Harker, R., Brookfield, P. & Tustin, S. 1993b. *Maturity of Royal Gala, Braeburn and Fuji – The New Zealand experience.* Proc. 9th Annu. Washington Treefruit Postharvest Conf. Wenatchee, 16-19 pp.

Watkins C.B., Erkan M., Nock J.F., Iungerman, K.A., Beaudry, R.M. & Moran, R.E. 2005. Harvest date effects on maturity, quality, and storage disorders of 'Honeycrisp' apples. *HortScience 40*; 164-169.

Weinger, F. & Wurm, L. 1998. Influence of different pruning methods on growth and flower bud supplement with the apple varieties Jonagold and Golden Delicious. *Mitteilungen-Klosterneuburg 48*; 172-178.

Westwood, M.N. 1993. *Temperate-Zone Promology: Physiology and culture.* Timber Press, Portl. and OR. 523 pp.

Willats, W.G.T., McCartney, L., Mackie, W. & Knox J.P. 2001. Pectin: cell biology and prospects for functional analysis. *Plant Molecular Biology 47*; 9-27.

Wills, R.B.H., Bambridge, P.A. & Scott, K.J. 1980. Use of flesh firmness and other objective tests to determine consumer acceptability of Delicious apples. *Aust. J. Exp. Agric. Anim. Husb. 20*; 252-256.

Wills, R.B.H., Hopkirk, G. & Scott, K.J. 1981. Reduction of soft scald in apples with antioxidants. *J. Amer. Soc. Hort. Sci. 106*; 569-571.

Wójcik, P., Rutkowski, K. & Treder, W. 2001. Quality and storability of 'Gala' apples as affected by crop load. *Folia Hort. 13*; 89-96.

Wünsche, J.N. & Lakso, A.N. 2000. The relationship between leaf area and high interception by spur and extension shoot leaves and apple orchard productivity. *HortScience 35*; 1202-1206.

Yamada, H., Ohmura, H., Ara, C. & Terui, M. 1994. Effect of preharvest fruit temperature on ripening, sugars, and occurrence of watercore in apples. *J. Amer. Soc. Hortic. Sci. 119*; 208-214.

Yamaki, S. 1995. Physiology and metabolism of fruit development. *Acta Hort. 385*, 109-120.

Yong, C.S. & Sy, C. 2000. The effect of mulching material on the shoot and root growth and fruit quality of 'Fugi'/M.26 apple. *J. Korean Soc. Hort. Sci. 41*; 512-516. (Abst).

Ystaas, J. 1992. Effects of summer pruning on yield, fruit size, & fruit quality of the apple cultivar 'Summerred'. *Acta Hort. 322*; 277-282.

Zhang, W. 1994. Apple impact bruise analysis. Ph.D. Dissertation. *Biological Systems Engineering Dept., College of Engineering & Architecture, Washington State University*, Pullman, WA.

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This thesis is based on the results of several experiments which were conducted in Kivik research station, SLU, during the period 1994 – 2005. The main aim was to improve the quality and storage potential of some apple cultivars in the area. Mulching methods, pruning dates, and fertigation systems as well as multi-practices orchard management models were investigated. Prediction of optimum harvest date by practicable method, and using postharvest heating as non chemical method against fungal decay were suggested.

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