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Harvest Time Influences Incidence of Storage Diseases and Fruit Quality in Organically Grown 'Aroma' Apples

J. Børve[1)], D. Røen[2)] and A. Stensvand[3)]
([1)]Norwegian Institute for Agricultural and Environmental Research, Lofthus, Norway, [2)]Njøs Fruit and Berry Development Centre, Leikanger, Norway and [3)]Norwegian Institute for Agricultural and Environmental Research, Ås, Norway)

Summary

In organic growing optimized harvest time might be an alternative method for avoiding storage diseases. In three years, organically grown apples of 'Aroma' were picked five times at one-week intervals, from two weeks prior to, to two weeks after recommended normal harvest time. The apples were cold stored until February 1 and then kept for two weeks at 20 °C. At harvest, fruit quality differed with harvest time, but after storage, time of harvest had no effect on fruit quality. In mean of three years, fruit decay after storage was significantly higher when picked after, compared to prior to recommended harvest time. The most important causes of postharvest fruit decay were *Colletotrichum acutatum* and *Neofabraea* spp.

Key words. *Colletotrichum acutatum* – fruit quality – *Malus* × *domestica* – *Neofabraea* spp. – physiological disorders

Introduction

The most important disease in Norwegian apple production is apple scab, and scab resistant cultivars are necessary for successful production of organically grown fruit in a cool, humid climate as in Norway. 'Aroma' has some field resistance to scab and is recommended as a major cultivar for organic apple production in Norway (Røen et al. 2004). However, it is susceptible to both physiological disorders and fungal fruit decay during storage (Landfald 1983). In organic apple production a limited number of fungicides are available, including sulphur. Sulphur has an effect against scab, but experiences from northern Germany indicate no effect against storage diseases (Maxin et al. 2005). Thus, organic growers need to rely on other management alternatives to control storage decays. Generally, late harvested apples are expected to develop more fruit rot than earlier harvested apples of the same cultivar. However, a clear relationship between harvest time and disease incidence has not always been found in experiments; it depends on cultivar, location, year and diseases present (Wilkinson and Sharples 1967; Gualanduzzi et al. 2005; Neri et al. 2005; Valiuskaite et al. 2006). In England, development of Neofabraea rot on apples inoculated with *Neofabraea perennans* (syn. *Gloeosporium perennans*) was promoted by delayed harvest time (Edney 1964).

Methods to determine an optimal harvest date differs from country to country. The Streif-index (Streif 1996) has been used to determine optimal harvest time in Switzerland (Höhn et al. 1999), Denmark (Kaack and Berthelsen 2004), Germany and the Netherlands (Tijskens et al. 2008) and has been reported from experiments in Belgium (Peirs et al. 2001), Canada (DeLong et al. 1999), Lithuania (Kviklene et al. 2008) and Spain (Alegre et al. 2006). The values proposed for apples for storage or direct sale differs between regions and cultivars, also within a country. Recommended Streif-indexes for 'Aroma' in Denmark were 0.07–0.12 (Kaack and Berthelsen 2004), but it was not specified if the apples were intended for direct use or storage. In Norway, the advisory service collects fruit samples in orchards and calculate Streif index regularly, and for 'Aroma' in Norway, a Streif-index of 0.11–0.12 is recommended for fruit going into storage, and an index of 0.07–0.09 for direct sale (Norwegian fruit advisory service, personal comm.).

The most important fungal diseases causing storage decay of conventionally grown apples in Norway were earlier reported to be bulls eye rot and lenticell-rot caused by *Neofabraea* spp. (Landfald 1983). Bitter rot was only occasionally found, and was believed to be caused by *Colletotrichum gloeosporioides* (Gjærum et al. 1967). Recent investigations have documented that bitter rot on apple in Norway is caused by *C. acutatum* (Stensvand et

al. 2006). Investigations in Norway have shown that bitter rot caused by *C. acutatum* was more important than earlier reported (Børve et al. 2008). Bulls eye rot, lenticell rot and bitter rot is reported to cause up to 30 % decay during a normal storage period of organically grown apples in northern Germany (Maxin et al. 2005).

The objective of the present experiments was to examine the influence of harvest time on development of storage diseases and fruit quality in organically grown apples of cv. 'Aroma'.

Materials and Methods

Over three years, apples of cv. 'Aroma' were picked in an organic orchard located in Ullensvang in southwestern Norway. The apples were harvested at weekly intervals from two weeks prior to anticipated optimal harvest time to two weeks after this time. Time of optimal harvest (hereafter named normal harvest time) was decided according to recommendations from the advisory service in the area, based on fruit sampling in the field 3–4 weeks prior to normal harvest time. Dates of first picking were September 14, 20, and 12 in 2004, 2005, and 2006, respectively.

At each time of harvesting, 65 apples were picked from each of three groups (replicates), each group including two or three trees. Apples from each group of trees were treated separately as replicates throughout the experiment. The apples were similar in development and representative for the stage of development in the orchard. Diseased fruits or fruits with visible injuries, e.g. caused by insects, were not stored. When the apples were placed in cold store, five fruit from each replicate and harvest time were removed to analyze background colour, cover colour, fruit firmness, soluble solids content and starch content. Background colour was assessed by giving subjective scores of colour from 1 to 9 in 2005 and 2006, 1 was green and 9 yellow. In 2004, a scale from 1 to 5 (made for 'Gala', Afcofel, Ctifl, France) was used for background colour, where 1 was green and 5 yellow. The scores were given by the same trained person during the whole season. Similarly coverage with red colour was scored by a scale from 1 (no red colour) to 9 (all surface covered with red) on each apple in 2005 and 2006. In 2004, a scale from 1 (no red colour) to 5 (whole surface red) (made for 'Gala', Afcofel, Ctifl, France) was used. Fruit firmness (kg cm^{-2}) was measured twice on opposite sides of each of the five apples, by a handheld penetrometer (Penfel, Copa Technologie, Saint Etienne du Gras, France), with a 1 cm^2 punch. Soluble solids content was analyzed on a mix of juice drops from each apple by a digital refractometer (PR 101, Atago Co., Ltd., Tokyo, Japan). The apples were cut in two halves and carefully dipped in iodine-solution. Starch content was judged by a scale from 1 to 10, where 1 was completely non-degraded starch (dark surface) and 10 no starch left (light surface) (Sørum 1985). Fruit firmness, sugar content and starch content were used to calculate Streif-index (Streif 1996) by the following formula: Fruit firmness (kg cm^{-2})/ (soluble solids content (%) × starch content (1–10, as indicated above)).

The remaining 60 apples were placed in two boxes, with no physical contact between the fruits, in one layer in each box. The boxes were stacked and placed in a ventilated dark cold room kept at 4 °C and covered with a plastic hood to maintain high humidity. At about November 15, December 15, January 15, and February 1, five apples from each replicate and harvest time were removed each time and used for similar quality assessments as at harvest, but starch content was not analyzed after the starch degradation was completed in November. Percentage of titrable acids in a mixed sample of the five apples was analyzed by use of a TTT6O Titrator, PHM Standard pH meter and ABU 80 Autoburette (Radiometer, Copenhagen, Denmark). February 1, the boxes were moved from 4 to 20 °C. All boxes were stacked and covered with plastic hoods at 20 °C. Each apple was numbered and followed through the whole storage period. Number of apples with different fungal diseases and physiological storage disorders were recorded about November 15, December 15, January 15, February 1 in the cold room, and about February 15 (at room temperature). Diseases were identified by symptoms and signs during the storage period and by use of a light microscope if necessary after the 2-week period at 20 °C. Some of the apples had severe physiological disorders, and they were divided in collapsed fruits or collapsed fruit with fungal growth. Fungal growth on such apples was likely due to secondary infections and was not included as fungal fruit decay. Occasionally apples with symptoms and signs of more than one fungal pathogen were found, and these were classified as infected with the fungus causing the presumably oldest and most severe disease development. Physiological disorders included soft scald and internal/senescent breakdown, but it was not distinguished between the physiological disorders. The plant protection scheme was similar each year, including regular applications with sulphur (Thiovit Jet, Syngenta, Basel, Switzerland, at a rate of 4.5 kg product per hectare) against scab from late April to mid-June (8, 7, and 5 times in 2004, 2005, and 2006, respectively).

Weather data were obtained from a weather station located at Ullensvang Research Centre (5 km from the orchard of sampling). Accumulated degree days from full bloom to each harvest date were calculated. Dates for full bloom in cv. 'Aroma' were May 13, 23, and 29 in 2004, 2005 and 2006, respectively.

Data were statistically analyzed by the GLM procedure of SAS (SAS Institute, Cary, NC, USA), and differences between means were separated by Student Newman Keuls method at $\alpha = 0.05$. Disease incidence data were arcsin square root transformed prior to analysis. All data presented are non-transformed means. Effect of harvest

time on fruit quality parameters recorded at different times during the storage season was analysed by repeated measurement on assessment time (with the GLM procedure). A correlation test was performed by the CORR procedure of SAS between degree days, total fruit decay and quality parameters (mean of 3 replicates) with year as replicate, providing Pearson correlation coefficients.

Results

Normal harvest was 138, 134, and 130 days after full bloom in 2004, 2005, and 2006, respectively. Difference from first to last picking in accumulated degree days was 252, 265, and 373 in 2004, 2005, and 2006, respectively.

Fruit quality

Background colour scores at harvest increased from the first to the last picking in the first two years. In the third year, the background colour was not recorded at the last picking time, and no differences between the other four picking times were found (Table 1). Cover colour scores increased significantly with picking time in two of three years (Table 1). Fruit firmness was significantly higher on fruit from the first two picking times than on fruit from the later picking times in 2005 and 2006 (Table 1). The same tendency was found in 2004, but the difference was not significant. No difference was found in content of soluble solids in apples from different harvest times in two of three years (Table 1). In 2006, apples picked two

Table 1. Fruit quality at harvest of organically grown 'Aroma' apples at five picking dates (2004–2006).

Year/ Harvest date	Background colour[a]	Cover colour[b]	Firmness (kg cm^{-2})[c]	Starch[d]	Soluble solids (%)	Streif-index[e]	Degree days[f]
2004							
September 14	1.5 b[g]	2.3 b	6.9	7.0 c	11.3	0.09 a	1794
September 21	1.6 b	1.8 b	6.7	7.9 bc	11.5	0.08 ab	1858
September 28	1.5 b	3.8 a	5.9	8.8 ab	11.2	0.06 bc	1935
October 5	2.0 b	3.3 a	5.8	9.7 a	11.4	0.05 c	1998
October 12	3.2 a	3.6 a	5.7	9.7 a	11.9	0.05 c	2046
P-value	0.0002	0.0003	0.0571	0.0013	0.6890	0.0017	–
2005							
September 20	7.3 c	6.6	8.0 a	4.0 b	12.5	0.17 a	1656
September 27	7.5 c	7.7	8.1 a	7.3 a	12.0	0.09 b	1728
October 4	6.7 d	6.5	6.7 b	7.4 a	13.1	0.07 b	1793
October 11	8.3 b	7.5	6.0 bc	–	12.8	–	1864
October 18	9.0 a	8.3	5.1 c	9.9 a	13.8	0.04 b	1921
P-value	0.0001	0.1004	0.0006	0.0039	0.0911	0.0104	–
2006							
September 12	6.2	7.3 c	6.3 a	2.7 c	10.6 b	0.26 a	1733
September 19	6.2	7.5 c	5.7 a	3.2 c	11.8 a	0.18 ab	1839
September 26	6.8	8.5 b	4.6 b	6.3 b	12.2 a	0.06 b	1943
October 3	8.0	8.5 b	4.2 b	7.3 ab	11.8 a	0.05 b	2031
October 10	–	9.0 a	3.9 b	8.3 a	12.0 a	0.04 b	2106
P-value	0.0458	0.0001	0.0005	0.0001	0.0006	0.0194	–

[a] A scale from 1 to 5 developed for 'Gala' (Afcofel, Ctifl, France) was used in 2004, a scale from 1 to 9 was used in 2005 and 2006; for both scales 1 is green and either 5 or 9 is yellow, respectively.
[b] A scale from 1 to 5 developed for 'Gala' (Afcofel, Ctifl) was used in 2004, a scale from 1 to 9 was used in 2005 and 2006; for both scales 1 is no red cover colour and either 5 or 9 is red cover over the whole surface.
[c] Measured by a hand held penetrometer on two sides of 5 apples.
[d] Starch scale from 1 to 10, where 1 is no degradation of starch and 10 complete degradation of starch.
[e] Streif-index = firmness/(starch * sugar).
[f] Mean day temperature accumulated from full bloom to harvest.
[g] Mean of 3 × 5 apples per harvest date. Mean values denoted with different letters within each parameter and year are significantly different according to Student Newman Keuls method at P = 0.05.

weeks prior to normal had lower soluble solids content than fruit from the other harvest times. Starch content of the fruit was higher at the first compared to the last picking all three years. Streif-index was highest at the first picking date and decreased with time of harvest (Table 1). Difference in calculated Streif-index from first to last picking was 0.04, 0.13, and 0.22 in 2004, 2005, and 2006, respectively. There were close correlations between Streif-index and harvest time, Streif-index and accumulated degrees days, and harvest time and degrees days, resulting in the following Pearson correlation coefficients: −0.74 (P = 0.002), −0.69 (P = 0.006), and 0.84 (P = 0.0001), respectively. Pearson correlation coefficient calculated on mean values of firmness and number of degree days at each harvest time was −0.85 (P = 0.0001).

At the end of the storage period, apples picked at different times were not significantly different in fruit quality. The time trend in fruit quality development, with decreasing firmness and acid content, increasing values of background colour and stable sugar value during storage, was similar for apples picked at all the different times, except for firmness in 2005 and 2006, where different picking time had significantly different slopes. In 2005 and 2006, apples picked prior to normal were significantly firmer at harvest and had steeper decrease in firmness from harvest to first assessment (mid-November) than firmness of apples picked at normal time or after normal time (data not shown).

Physiological disorders

Incidence of physiological disorders increased during storage. At the end of cold storage the incidence of physiological disorders was significantly higher when harvested two weeks after normal time compared to the other harvest times in 2004 (data not shown). Also after two weeks at 20 °C it was higher incidence of physiological disorders on apples picked two weeks after normal time (Table 2). There was no difference in physiological disorders between different harvest times in 2005 and 2006 (Table 2).

Fungal fruit decay

The amount of decayed fruit was low for assessments November 15, December 15, and January 15 (data not shown). The first symptoms of bitter rot were recorded about January 15, February 1, and December 15 for fruit harvested in 2004, 2005, and 2006, respectively. Similarly, dates for first Neofabraea rot detected was about December 15, January 15, and February 15, respectively. Apples that developed grey mould were completely decayed about November 15 all three years. At the end of cold storage (about February 1), apples picked before normal and at normal harvest time had significantly less total fungal fruit decay than apples picked one or two weeks after normal harvest in mean of three years (Fig. 1).

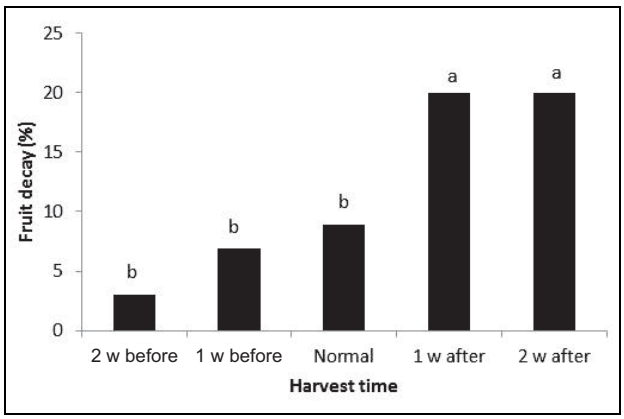


Fig. 1. Total fungal fruit decay (%) on organic apples of cv. 'Aroma' harvested over 5 weeks (at normal harvest time, 1 or 2 weeks (w) before or 1 or 2 w after) and stored at 4 °C until February 1 (4 months). Mean of 3 years and 3 × 40 apples at each harvest time, each year. Mean values with different letters are significantly different according to Student Newman Keuls method at P = 0.05.

After two weeks at 20 °C, the total number of decayed fruit was significantly higher (P = 0.0001) when picked two weeks after normal harvest time compared to two weeks before (mean of the three years). Incidence of bitter rot was significantly lower (P = 0.0001) when apples were picked two or one week prior to normal harvest time than later pickings (mean of three years). Incidence of Neofabraea rot was significantly lower (P = 0.05) for apples picked two weeks prior to normal harvest time compared to two weeks after normal harvest (mean of three years) (Fig. 2). Harvest time significantly influenced total fruit decay in 2004 and 2006, but not in 2005 (Table 2). Incidence of bitter rot was lower on apples picked prior to than after normal time in 2004 (Table 2), but there were no significant differences between harvest times the other two years. Incidence of other diseases was not different with different harvest times, except for more blue mould (caused by *Penicillium* sp.) if picked two weeks after normal harvest time compared to the other picking times (Table 2). Total fruit decay at the end of storage was correlated with firmness, degree days, starch content and Streif-index, giving the following Pearson correlation coefficients: −0.65 (P = 0.0084), 0.89 (P = 0.0001), 0.69 (P = 0.0066) and −0.66 (P = 0.0096), respectively.

Discussion

The present experiments documented that harvest time clearly influenced development of fungal fruit decay during storage in organically grown apples of 'Aroma'. Total fruit decay in apple increased significantly with delayed harvest in experiments in Lithuania (Valiuskaite

Table 2. Incidence (%) of fruit decay in organically grown apples of cv. 'Aroma', harvested weekly over a five week period (at normal harvest time, 1 or 2 weeks before or 1 or 2 weeks after) and assessed after 4 months at 4 °C followed by 2 weeks at 20 °C in 2004–2006.

Year/ Harvest date	Total fruit rot	Bitter rot[a]	Neofabraea rot[a]	Grey mould[a]	Physiological disorders	Others[a]	
2004						Brown	Fus
September 14	20.0 d[b]	3.3 c	3.3	0.0	1.2 b	13.9	0.0
September 21	35.0 b	20.0 bc	10.0	0.0	2.5 b	9.9	0.0
September 28	57.5 b	39.2 ab	8.3	0.0	5.0 b	8.3	0.0
October 5	86.7 a	64.2 a	6.7	0.0	7.5 b	8.3	0.0
October 12	90.0 a	48.3 a	14.2	0.8	19.2 a	13.9	1.7
P-value	0.0001	0.0006	0.2439	0.4609	0.0396	0.7318	0.4609
2005						Brown	Fus
September 20	17.5	1.7	6.7	0.0	10.0	9.2	0.0
September 27	33.3	6.7	8.3	0.0	6.7	17.5	0.8
October 4	50.0	20.0	12.5	0.0	14.2	10.8	5.0
October 11	46.7	12.5	15.8	0.0	26.7	15.0	2.5
October 18	51.7	9.2	29.2	1.7	10.8	10.8	0.8
P-value	0.1129	0.1764	0.1521	0.4609	0.3042	0.7152	0.1929
2006						Mon	Pen
September 12	25.8 b	13.3	2.5	0.8	5.8	0.0	0.0 b
September 19	36.7 b	14.7	7.5	0.8	4.2	0.0	0.8 b
September 26	58.3 ab	40.8	2.5	1.7	6.7	0.0	0.8 b
October 3	63.3 ab	28.3	5.0	11.7	5.8	0.0	4.2 b
October 10	75.8 a	42.5	3.3	2.5	8.3	1.7	15.8 a
P-value	0.0202	0.1664	0.6172	0.1140	0.7582	0.4609	0.0087

[a] Bitter rot caused by *Colletotrichum acutatum*, Neofabraea rot caused by *Neofabraea* spp., grey mould caused by *Botrytis cinerea*, Brown unidentified rot spots (Brown) caused by an unidentified organism, Brown rot (Mon) caused by *Monilinia fructigena*, Blue mold (Pen) caused by *Penicillium* sp. and Fusarium rot (Fus) caused by *Fusarium* sp.

[b] Mean of 3 × 40 apples per harvest date. Mean values within each decay and year denoted with different letters are significantly different according to Student Newman Keuls method at P = 0.05. Incidences were arcsin square root transformed prior to analysis, presented values are non-transformed means.

et al. 2006) and UK (Wilkinson and Sharples 1967). A comparison between early, normal and late harvested 'Gala' apples produced conventionally in Italy, showed significantly higher rot incidence if apples were harvested late (Neri et al. 2005). The same tendency, although not statistically significant, was observed in 'Pink Lady' (Gualanduzzi et al. 2005). In both experiments in Italy, the main cause of decay was *N. alba*. The most commonly found diseases in the present experiment were bitter rot in 2004 and 2006, and Neofabraea rot, mostly caused by *N. perennans*, in 2005. We are not aware of any previously reported experiments including harvest time and bitter rot. However, in one earlier experiment it was not distinguished between the three pathogens causing "*Gloeosporium*-rot" (Wilkinson and Sharples 1967), and bitter rot caused by *C. gloeosporioides* may have been present.

In the present experiments, harvest time did not seem to influence disease development of other diseases, except that a high amount of blue mould was found on apples picked late in 2006. The other diseases found to some extent here were grey mould (one year) and Fusarium rot (one year). In Lithuania, harvest time had no effect on incidence of either blue mould or grey mould in 'Ligol' and 'Lodel' (Valiuskaite et al. 2006). After storing two weeks at room temperature following the period in cold store, a high number of brown spots developed in two years, and these may possibly have developed into Neofabraea rot or bitter rot if they had been kept for a longer time at high temperature.

Apple fruit also need to have suitable quality for eating at end of the storage period. In the present experiments, picking started two weeks earlier than the esti-

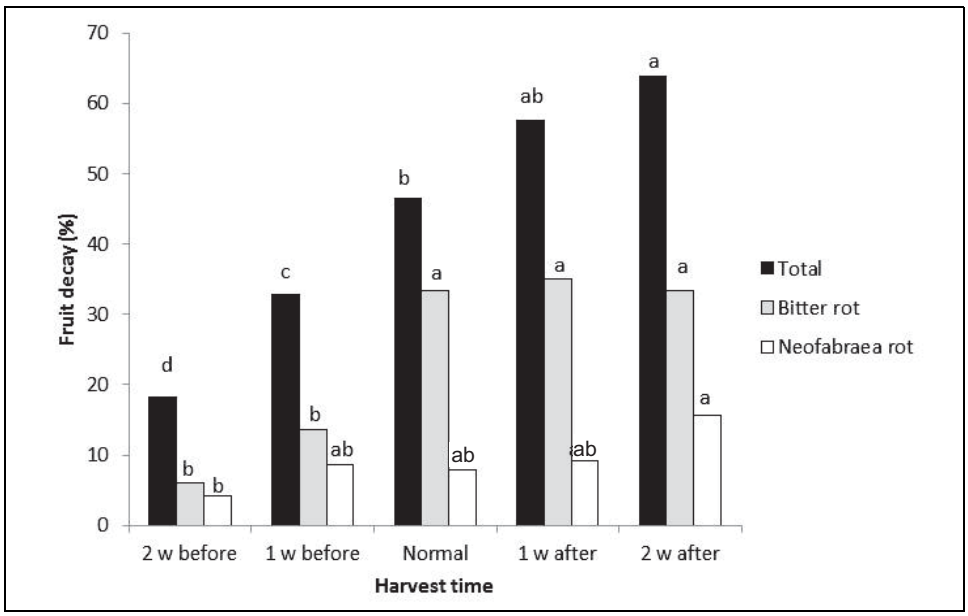


Fig. 2. Total fungal fruit decay, bitter rot and Neofabraea rot (%) on organic apples of 'Aroma' harvested over 5 weeks (at normal harvest time, 1 or 2 weeks (w) before or 1 or 2 w after) and stored at 4 °C until February 1 (4 months) and two weeks at 20 °C. Mean of 3 years and 3 × 40 apples at each harvest time, each year. Mean values with different letters within each decay are significantly different according to Student Newman Keuls method at P = 0.05.

mated normal harvest. However, according to the local advisory service's recommended optimal values of the Streif-index, harvest started too late in 2004. Both in 2004 and 2006 the Streif-index was below optimal values for direct sale before estimated optimal harvest time. Thus, the Streif-index used alone might not be a fine tuned enough tool to determine optimal harvest time.

Another tool for determination of optimal harvest date is by calculating degree days from full bloom to harvest (Kaack and Berthelsen 2004). Number of days from full bloom to harvest and number of degree days were higher at first picking in 2004 than for the other two years. First picking in 2004 had also lower Streif-index than the next two years (not compared statistically). The difference in accumulated degree days from first to last picking was highest in 2006 (373) and lower in 2004 and 2005 (252 and 265, respectively). The difference in Streif-index from first to last picking was highest in 2006 and lowest in 2004. The recommended Streif-index intervals for harvest of cv. 'Aroma' for direct sale (0.07–0.09) were about 129 days after full bloom each year of the experiments. Number of degree days at same time was about 200 degrees higher in 2006 than in 2004 and 2005. In the present experiment, number of days from full bloom was more precise than degrees days for estimating optimal harvest date.

Conclusion

These results show that organically grown 'Aroma' apples can be stored successfully if harvested early, thus supporting the local market with fresh fruit and juice producers with fruit for freshly made juice over a long period.

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Addresses of authors: Jorunn Børve (corresponding author), Norwegian Institute for Agricultural and Environmental Research, Ullensvang, N-5781 Lofthus, Norway, D. Røen, Njøs Fruit and Berry Development Centre, Njøsavegen 5, N-6863 Leikanger, Norway, and A. Stensvand, Norwegian Institute for Agricultural and Environmental Research, Høgskoleveien 7, N-1432 Ås, Norway, e-mail (corresponding author): Jorunn.Borve@bioforsk.no.