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Preharvest application with calcium and maturity at harvest affects postharvest fungal fruit decay of European plum

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Abstract The combination of preharvest treatments with calcium chloride and fungicides, and storage of maturity graded fruit were assessed in five European plum cultivars. At harvest, samples of fruit within a commercially suitable range in ripening were divided into two categories: less-ripe (tree ripe-) and more-ripe (tree ripe+). The fruit were stored for 10–14 days at 4 °C followed by 2–3 days at 20 °C before the assessment of fungal decay. If calcium chloride was applied six times each season, postharvest fruit decay was significantly reduced in four of nine experiments, with a total mean reduction of around 50%. Two calcium applications in combination with a fungicide treatment reduced decay by approx. 60% compared to the untreated in one experiment. In six of seven experiments there was no effect of preharvest fungicide applications. In six of 10 experiments, fruit of the category tree ripe- had fewer fruit with fungal decay after storage than the tree ripe+fruit. The higher incidence in the category tree ripe+fruit was primarily due to brown rot, Mucor rot, and blue mould. For the category tree ripe+, there was two to ten times more decay than on tree ripe- fruit after a simulated shelf-life period. To ensure low incidence of fungal decay, fruit of commercial harvest maturity may thus be separated in two ripening categories, one for rapid distribution to the market (tree ripe+) and another for extended distribution time (tree ripe-).

Keywords *Botrytis cinerea* · I_{AD}-index · *Monilinia* spp. · *Mucor piriformis* · *Prunus domestica*

Introduction

In Norway, domestically produced cultivars of European plum (*Prunus domestica* L.) are marketed for fresh consumption within 2—3 weeks after harvest. Fungal fruit decay and softening (over-ripening) are important factors limiting the length of time plums are available for marketing (Vangdal et al., 2007a). To ensure a long sales period of high-quality fruit, preharvest applications with synthetic fungicides are commonly done. Fruit is harvested at the recommended optimal time, and the criteria for timing of harvest are based on observations of color and firmness (Vangdal & Flatland, 2010).

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Fungal fruit decay observed on plum after storage in Norway include brown rot (*Monilinia* spp.), grey mould (*Botrytis* sp.), blue mould (*Penicillium* sp.), Mucor rot (*Mucor piriformis*) and anthracnose (*Colletotrichum acutatum*) (Børve & Vangdal, 2007).

Applications of calcium have been proposed as a means to reduce postharvest fungal decay and improve fruit quality in plum (Vangdal & Børve, 2002; Wojcik, 2001) and peach (Conway et al., 1987; Elmer et al., 2007; Hemat et al., 2014). Calcium may both enhance resistance against decay and have a direct fungicidal effect. The latter was documented *in vitro* for *Botrytis cinerea* (Wiesniewski et al., 1995), *Penicillium expansum* (Stošić et al., 2014; Wiesniewski et al., 1995), *Colletotrichum acutatum* (Biggs, 1999; Stošić et al., 2014), *Monilinia fructicola* (Biggs et al., 1997), and *Rhizopus stolonifer* (Tian et al., 2002). It has been proposed that the increase in disease resistance following calcium applications may be due to changes in cell degrading enzymes and firmness (Conway et al., 1994; Hocking et al., 2016).

European plum cultivars produced in Norway and used for fresh consumption are picked within a certain range in maturity when delivered to packinghouses for grading and packing. Following grading, over-ripe fruit are discarded, while under-ripe fruit are stored for further ripening before marketed. Fruit ripening leads to senescence and cell deterioration, providing tissues well suited for infection of fungal pathogens (Alkam & Fortes, 2015). More mature fruit may therefore develop fungal decay faster than less mature fruit, as documented for brown rot on peach (Gradziel, 1994). Introduction of non-destructive assessment of fruit ripening has provided a possibility to follow maturation on the trees, as e.g., in peach (Ziosi et al., 2008), and to sort fruit according to ripening status at harvest (Spadoni et al., 2016). The effect of smaller differences in maturity on fungal decay among fruit harvested at the same time is less studied; however, in peach a close relationship was found between fruit ripening and brown rot (Spadoni et al., 2016). The objective of the present investigation was to show how preharvest applications of calcium in combination with maturity grading at harvest may affect postharvest fungal fruit decay in European plum.

Materials and methods

Experimental design

Experiments were performed in a research orchard at NIBIO Ullensvang in southwestern Norway on trees planted in 2008, trained as slender spindle, and with a planting distance of 2 × 4.5 m. All trees were on rootstock St. Julien A, and the following cultivars were included (years when included in the experiments in parentheses): Avalon (2013), Jubileum (2014–2015), Mallard (2013–2015), Opal (2013–2015), and Reeves (2013). Each cultivar and year-combination were considered as an independent experiment, with 10 experiments in total. The cultivars were planted in at least three rows (about 30 trees in each row), and the rows were replicates in the experiments. The orchard was treated as commercial practice in the region, but no fungicides were applied in the experimental period, i.e., from about three weeks after full bloom until harvest. Before the experimental period, the trees were treated with a copper fungicide at bud burst and with a synthetic fungicide during flowering. In treatments with calcium (Ca), 2.1 kg/ha of the product CC road® (77% $CaCl_2$, TETRA Chemicals Europe, Helsingborg, Sweden) was applied three or six times. Furthermore, in several experiments the fungicides boscalid + pyraclostrobin (Signum, 267 + 67 g/kg active ingredient, a.i., BASF, Ludwigshafen, Germany) and fenhexamid (Teldor, 500 g/kg a.i., Bayer Crop Science, Monheim, Germany) were applied at rates of 1.5 kg/ha of the products one or two times per season. A tractor mounted sprayer (Osella ATM 3PP 500, Torre de' Picenardi, Italy) was used for the calcium and fungicide applications.

In four of the ten experiments, there was a split plot design with Ca or no Ca as the plot treatments and different fungicide applications as subplot treatments (suppl. Figure 1A); trees of cvs. Opal and Reeves in 2013 and Jubileum in 2014 and 2015 were divided in two groups with 45 trees in each plot. One plot received foliar applications of Ca six times from about 12 weeks prior to harvest, while the other plot did not receive any Ca treatments. The Ca applications were performed every second week starting from the end of May or mid-June, depending on how early the season was. In the subplots, four (three in cv. Jubileum in 2015) fungicide treatments were performed in a fully randomized design with three

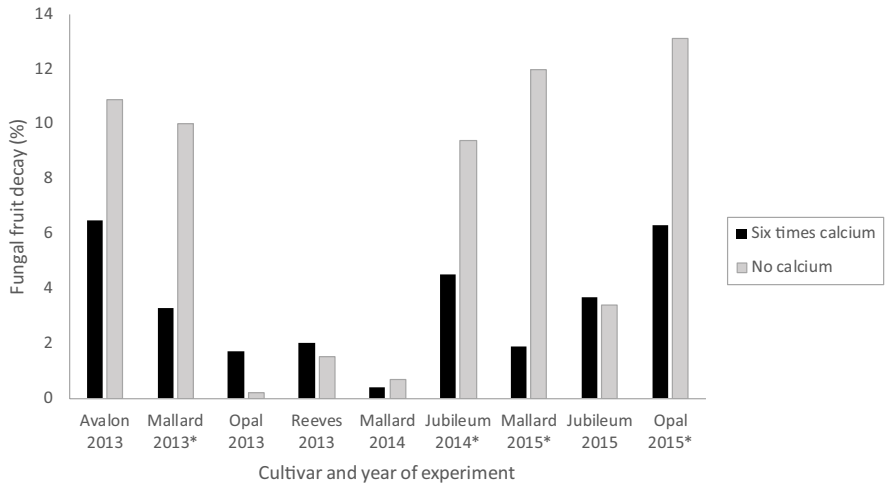

Fig. 1 Effect of foliar application of calcium chloride six times prior to harvest on fungal fruit decay (%) after storage for 10–14 days at 4 °C and 2–3 days at 20 °C. Mean of 3 or 4 replicates × 100 fruit in nine different experiments in 2013 – 2015, using five different cultivars of European plum. Cultivar and year combinations with an asterisk (*) marks significant differences ($P \leq 0.05$) between treated and non-treated with calcium

replicates (Table 1). Boscalid + pyraclostrobin and fenhexamid were each used either one or two times. Each sub-plot consisted of two trees in the same row with an unsprayed guard tree between each unit in the row.

For cv. Opal in 2014, treated and untreated plots included 45 trees each (suppl. Figure 1B). The treated plot included two applications with Ca (four and two weeks prior to harvest) and one with boscalid + pyraclostrobin 10 days prior to harvest. For each of the two plots (treated and untreated), fruit were sampled in nine randomly distributed replicates, each including two trees. The following year, trees of cv. Opal were divided in three main plots (30 trees in each) (suppl. Figure 1C). The trees were treated either three or six times with Ca or kept untreated. Subplots of two trees in the three plots were either treated one time with boscalid + pyraclostrobin 14 days prior to harvest or kept untreated in a randomized block design with four replicates.

In each of the four remaining experiments, treatments were replicated tree times in a fully randomized block design, with two trees in each plot and with one unsprayed guard tree between each plot in the row (suppl. Figure 1D). In 2013, treatments with cvs. Mallard and Avalon were either six times with

Table 1 Design of experiments with foliar calcium chloride and synthetic fungicides[1] in three European plum cultivars in 2013–2015

Cultivar	Year	Plots	Treatments in subplots within the plots			
Opal	2013	Calcium	Unsprayed	bo + py 10d[2]	bo + py earl	bo + py both times
		Unsprayed	Unsprayed	bo + py 10d	bo + py early	bo + py both times
Reeves	2013	Calcium	Unsprayed	bo + py 10d	bo + py early	bo + py both times
		Unsprayed	Unsprayed	bo + py 10d	bo + py early	bo + py both times
Jubileum	2014	Calcium	Unsprayed	bo + py 10d	bo + py 20d	bo + py 12wks
		Unsprayed	Unsprayed	bo + py 10d	bo + py 20d	bo + py 12wks
Jubileum	2015	Calcium	Unsprayed	bo + py 14d	fen 30d	-
		Unsprayed	Unsprayed	bo + py 14d	fen 30d	-

[1]A tractor mounted sprayer was used for six foliar applications of calcium as 2.1 kg/ha of CC road® (77% $CaCl_2$, TETRA Chemicals Europe) at two-week intervals and with boscalid + pyraclostrobin (bo + py, BASF) and fenhexamid (fen, Bayer Crop Science) at recommended rates

[2]d is days prior to harvest, wks is weeks prior to harvest, early is four weeks after bloom

Ca at two-week intervals from 12 weeks prior to harvest or untreated. On cv. Mallard in 2014 and 2015, three treatments were compared with the untreated; Ca (six times from about 12 weeks prior to harvest), boscalid + pyraclostrobin (10 or 14 days prior to harvest), and a combination of the two.

Assessments

One to four days before start of harvest, trees in the different experimental units were visually observed for fungal decay on the fruit. Furthermore, the condition of each tree was observed, especially for potential phytotoxic effects along edges of the leaf blades due to Ca applications, and yield on each tree was estimated roughly as a percentage of full yield potential of the trees. Harvest time of the different cultivars differed among years, but the order when the different cultivars were harvested was the same. About 40 to 60% of the yield suitable for marketing was harvested, including a low percentage of overripe fruit which were discarded. Fruit from each experimental unit were subdivided into two categories, either less- (tree ripe-) or more-ripe (tree ripe+). Maturity grading was done manually by visually observing background color and gently feeling the fruit firmness. The intention was to include 100 fruit of each ripening degree from each experimental unit; however, some samples had fewer than 100 fruit (most often of tree ripe+), but never less than 25 fruit. The fruit were placed in boxes normally used for 6 kg of loosely packed plums (IFCO 4313). Depending on size, the fruit were laid on top of each other in two layers or were kept in a single layer. Possible contact contamination between fruit was thus not prevented during storage.

The fruit samples were stored at 4 °C for 10–14 days, followed by 2–3 days at 20 °C; simulating a sales period, after which number of fruit with visible fungal decay was counted. Identification of fungal decay was based on symptoms and macroscopic signs of the fungi, and if necessary, confirmed by microscopy.

Fruit quality analysis

Before storage, a 10-fruit sample from each of the ripening degrees from each experimental unit was analyzed. In 2013, firmness was analyzed with a DUROFEL DFT 100 penetrometer (Agro Instruments, Serqueux, France) with a 6-mm punch, giving values from 0 to 100. The following two years, a FirmTech 2 Fruit Firmness Tester (Wameco, Kansas, USA) was used, giving values of g/mm from 0 to 1000. For both instruments higher values indicated firm fruit.

Subjective scales (1 to 9) were used for both background color (1 = green and 9 = yellow) and cover color (1 = up to 10% and 9 = 100%). In addition, all fruit were analyzed with a portable spectrometer, a DA-Meter (version 1.0 in 2013 and 2014 and version 1.4 in 2015, TR-Turoni snc., Forli, Italy), measuring I_{AD}-index, the difference in absorbance at 720 and at 670 nm, which is an indicator of green background color. Soluble solid content in juice from each 10-fruit sample was recorded with a refractometer (PR 101, Atago Co. Ltd., Tokyo, Japan). Another 10-fruit sample from each experimental unit was also analyzed for the same quality parameters, either after the cold storage period, after the days at room temperature, or both. After storage, the remaining fruit were assessed for internal damage of the fruit flesh, including flesh browning, internal breakdown, or other disorders.

Statistical analysis

Data from each experiment (each cultivar and year combination) were analyzed separately and as mean of all. Analysis of variance for the factors and their interaction was performed by the GLM procedure in SAS (9.4 SAS Institute, Cary, North Carolina, USA). Means were separated by Student Newman Keul's method at $P = 0.05$. Incidence data were arcsin-square root transformed prior to analysis. Presented data are non-transformed values.

Results

In the experiments performed in three growing seasons the following diseases (causal pathogens in parentheses) were observed: Brown rot (*Monilinia* spp.), Mucor rot (*Mucor* sp.), blue mould (*Penicillium* sp.), grey mould (*Botrytis* sp.) and Cladosporium rot (*Cladosporium* sp.).

Effect of calcium and fungicide treatments

Six applications of $CaCl_2$ significantly reduced total fungal fruit decay after storage in four of nine experiments (Fig. 1). In comparison with the untreated, fruit treated with Ca were significantly larger in four experiments (cvs. Avalon 2013, Opal 2013, Reeves 2013, Jubileum 2014), contained less soluble solids in two experiments (cvs. Opal 2013, Jubileum 2014), had more green background color in six experiments (cvs. Mallard 2013, Opal 2013, Reeves 2013, Jubileum 2014, Jubileum 2015, Mallard 2015), and had firmer fruit in four experiments (cvs. Jubileum 2014, Opal 2015, Jubileum 2015, Mallard 2015) ($P \leq 0.05$, data not shown). In the other experiments, there were no significant differences between calcium treated or non-treated fruit.

In the experiment where three applications with Ca were included as one treatment (cv. Opal 2015), there was no significant difference between three applications and untreated in fungal fruit decay following the simulated storage and sales period. In the one experiment where two applications with Ca and one with a fungicide were compared with the untreated (Opal 2014), fungal fruit decay was about 2.5 times higher on fruit from untreated trees ($P = 0.0001$). In six of the seven experiments including fungicides in subplots, there was no significant reduction in fruit decay. In one experiment (cv. Opal 2015), total fungal fruit decay was reduced from 13% in the untreated to 1.7% when fungicides were applied ($P = 0.0001$).

Effect of maturity grading

Total fungal fruit decay was higher in fruit of the more-ripe (tree ripe+) compared to the less-ripe category (tree ripe-) after storage and the simulated sales period in six of 10 experiments (Fig. 2). In mean of all experiments, incidence of fungal fruit decay was 4.5 times higher for fruit of the category tree ripe+ than tree ripe- ($P = 0.0001$).

The two ripening categories were different in fruit quality when assessed after grading but before storage, except for fruit size on cv. Opal in 2013 and cv. Jubileum in 2015, and soluble solids content of cvs. Avalon, Reeves, and Mallard in 2013, and Jubileum in 2015 (Table 2). In general, more-ripe fruit had more cover color, more yellow background color, lower I_{AD}-index, lower firmness, higher soluble solids content, and larger fruit size (Table 2). After storage, there were still differences between the two ripening categories for fruit quality parameters, but continued ripening had diminished the differences, e.g., in background color (data not shown).

In the six experiments where there were significant differences in fruit decay between the two categories tree ripe+ and tree ripe- (Fig. 2), there was a higher incidence of brown rot on the more-ripe fruit in four experiments, Mucor rot in three, blue mould in four, grey mould in two, Cladosporium rot in one, and unidentified causes of decay in three of the experiments (Table 3). Incidence of physiological disorders (e.g., internal breakdown) was insignificant (data not shown).

Discussion

The mean reduction in postharvest fungal fruit decay was approximately 50% when applying Ca six times in the field, and the decay was reduced by close to 80% in less-mature compared to more-mature fruit if they were subdivided in the two ripening categories before storage. This is the first documentation of differences in fruit quality and storability of plum fruit picked within a range in commercially acceptable maturity. It is also the first report of a relationship between ripening degree of plum fruit and postharvest development of fungal fruit decay in general and for brown rot, grey mould, Mucor rot, blue mould and Cladosporium rot specifically.

Opposite to Ca treatments, the effect of preharvest fungicide applications on postharvest decay in plum in the present experiments was low or insignificant, as reported earlier, e.g., by Borecka et al. (1991). Experiments with Salicina plum (*Prunus salicina*) cultivars in South Africa showed that few latent infections of *M. laxa* will establish early in the fruit development period compared to in other stone fruits (Schlagbauer & Holz, 1989). Also, for *B. cinerea* it was shown that infections occurred at later fruit development stages, e.g., from around four weeks prior to harvest (Fourie & Holz, 1998), but most frequently during the last two weeks prior to harvest (Fourie et al., 2002). This indicates that primarily late fungicide applications may reduce postharvest fruit rot in plum.

Table 2 Fruit quality of European plum cvs. Opal, Jubileum, Reeves, Avalon and Mallard harvested within a commercial suitable range and subdivided into two ripening categories in 2013 to 2015

Fruit quality at start of storage												
Ripening category[1]	Cover color[2]	Background color[3]	I_{AD} – index[4]	Firmness[5]	Soluble solids (%)	Fruit size (g)	Cover color	Background color	I_{AD}-index	Firmness	Soluble solids (%)	Fruit size (g)
	Opal, 2013						Reeves, 2013					
Tree ripe-	4.0[6]	5.6	0.55	71.2	13.2	31.2	3.9	6.1	0.35	71.0	12.2	59.1
Tree ripe+	4.6	8.4	0.34	61.4	14.2	32.2	6.3	8.1	0.18	60.3	12.6	62.6
P-value	0.0007	0.0001	0.0001	0.0001	0.0001	0.2506	0.0001	0.0001	0.0001	0.0001	0.1141	0.0007
	Opal, 2014						Avalon, 2013					
Tree ripe-	4.4	3.6	0.61	444	14.5	38.4	2.6	3.0	-[7]	74.5	14.9	51.3
Tree ripe+	6.4	8.2	0.36	286	17.3	41.3	6.9	6.0	-	59.0	14.8	58.1
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0005	0.0001	0.0001		0.0001	0.7837	0.0001
	Opal, 2015						Mallard, 2013					
Tree ripe-	3.8	3.7	0.57	495	11.4	40.3	4.4	4.3	0.79	-	14.6	46.2
Tree ripe+	6.9	7.0	0.26	385	12.4	43.1	6.7	7.9	0.57	-	14.6	48.6
P-value	0.0001	0.0001	0.0006	0.0001	0.0001	0.0009	0.0001	0.0001	0.0001		0.7872	0.0446
	Jubileum, 2014						Mallard, 2014					
Tree ripe-	7.3	8.0	0.33	408	14.2	82.1	4.4	2.8	1.05	536	15.8	40.0
Tree ripe+	8.8	8.9	0.31	346	15.8	96.5	6.8	5.5	0.85	373	17.7	41.2
P-value	0.0001	0.0001	0.0493	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0059
	Jubileum, 2015						Mallard, 2015					
Tree ripe-	7.7	7.5	0.26	547	13.3	81.2	4.9	3.2	0.99	464	14.1	53.9
Tree ripe+	8.5	8.6	0.19	446	13.8	85.1	8.1	6.6	0.76	309	15.9	56.8
P-value	0.0001	0.0001	0.0001	0.0001	0.0545	0.0884	0.0001	0.0001	0.0001	0.0001	0.0002	0.0217

[1]Separation of the fruit in ripening category tree ripe- (less-ripe) and tree ripe+ (more-ripe) was tactile and based on observation of background color and gently pressing with fingers to feel firmness of the fruit

[2]Scored subjectively by a scale from 1 to 9, where 1 is 10% and 9 is 100% coverage of red/blue

[3]Scored subjectively by a scale from 1 to 9 where 1 is green and 9 is yellow

[4]I_{AD}-index was obtained by use of a DA-Meter (TR-Turoni snc, Forli, Italy). The index was a difference in absorbance (670 nm – 720 nm), providing an indicator of green skin colour and thus fruit ripeness

[5]Firmness was expressed as DUROFEL units (0–100) in 2013 and g/mm in 2014 and 2015 (0–1000, by FirmTech 2)

[6]Mean of 3 to 4 (9 for Opal in 2014) replicates per experimental unit in split plot design and in total 6 to 24 samples

[7]Not assessed

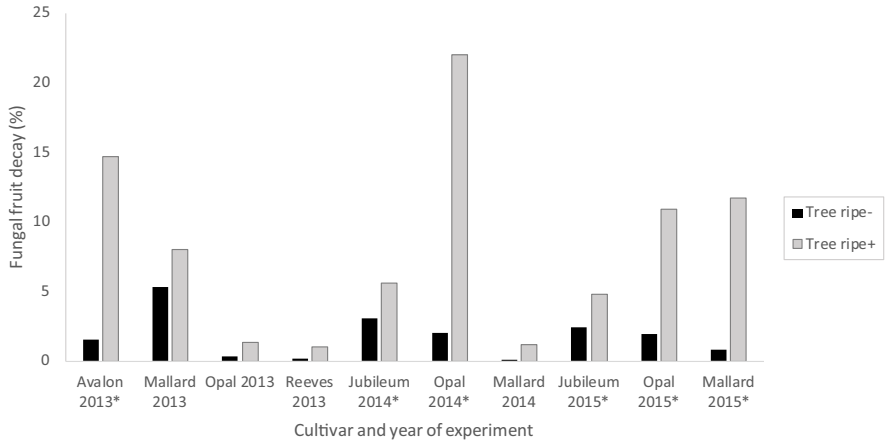

Fig. 2 Effect of ripening degree on fungal fruit decay (%) after storage for 10–14 days at 4 °C and 2–3 days at 20 °C. Mean of 3 or 4 (9 for Opal 2014) replicates × 100 fruit in nine different experiments in 2013 – 2015, using five different cultivars of European plum. Cultivar and year combinations with an asterisk (*) marks significant differences ($P \leq 0.05$) between fruit classified as tree ripe- and tree ripe+

The positive effect of Ca was likely rather due to increased resistance, as proposed by Conway et al. (1994), than a direct fungicidal effect. The present experiments also showed that the fruit ripening may be slowed by the application of Ca, thus possibly reducing fungal fruit decay postharvest, as documented by Sinha et al. (2019) in India. In the present experiments, foliar calcium applications reduced postharvest incidence of fungal fruit decay on cvs. Jubileum, Opal, and Mallard. Earlier experiments in Norway with cv. Opal (Vangdal & Børve, 2002) and cv. Mallard (Vangdal et al., 2007b) showed a similar

Table 3 Fungal fruit decay of European plum cvs. Avalon, Opal, Jubileum and Mallard after storing fruit in two categories of ripening for 10—14 days at 4 °C and 2—3 days at 20 °C

		Fungal fruit decay (%)					
Cultivar, year	Ripening category[1]	Brown rot	Mucor rot	Blue mould	Grey mould	Cladosporium rot	Unidentified rot[2]
Avalon, 2013	Tree ripe-	0[3]	0	0	0	0	1.5
	Tree ripe+	0.7	0.2	0	2.0	0	11.8
	P-value	0.2094	0.3506	-	0.0711	-	0.0004
Opal, 2014	Tree ripe-	1.6	0.2	0.1	0.3	0	0
	Tree ripe+	11.7	5.9	3.8	0.9	0.1	0
	P-value	0.0001	0.0001	0.0059	0.3077	0.3256	-
Opal, 2015	Tree ripe-	1.7	0	0	0.2	0	0
	Tree ripe+	7.9	0.1	0.5	1.5	0	0.9
	P-value	0.0001	0.3285	0.0550	0.0003	-	0.0021
Jubileum, 2014	Tree ripe-	0.9	1.2	0.3	0.3	0	0.1
	Tree ripe+	1.3	3.6	0.5	0.5	0.1	0
	P-value	0.8859	0.0057	0.5183	0.8432	0.3233	0.5083
Jubileum, 2015	Tree ripe-	1.1	0	0	0.6	0	0.2
	Tree ripe+	2.0	0	0	0.8	0	1.5
	P-value	0.3450	-	-	0.9330	-	0.0006
Mallard, 2015	Tree ripe-	0.2	0	0.1	0.3	0	0.2
	Tree ripe+	5.3	0.9	1.3	0.3	3.7	0.3
	P-value	0.0496	0.0814	0.0126	1.0000	0.0111	0.8269

[1]Separation of the fruit in ripening category tree ripe- (less-ripe) and tree ripe+ (more-ripe) was tactile and based on observation of background colour and gently pressing with fingers to feel firmness of the fruit

[2]Small lesions with no symptoms or fungal growth that identified the disease/pathogen at time of assessment

[3]Mean of 3—4 (9 of cv. Opal in 2014) replicates from split plot experiments, each sample had 100 fruit

reduction in decay following Ca applications. In those experiments, one to three applications of Ca were performed, while up to six applications were included in the present experiments. No effects on fruit quality parameters by Ca were observed by Vangdal et al. (2007b) on cv. Mallard, but experiments in Poland showed that Ca increased firmness and soluble solids content of European plum fruit (Wojcik, 2001). In the present experiments, fruit had a delayed ripening if treated with Ca, and this may explain the lower soluble solids content found in two of the experiments when Ca was applied. We observed that leaf blade edges in Ca treated trees sometimes were slightly necrotic (data not shown), but if that affected the photosynthetic activity negatively is not clear. Increased fruit size was found in Ca treated trees in three experiments. Yield may affect fruit size, but no yield differences were observed. The total effect of Ca applications was positive, and to reduce the risk of fungicide residues it may thus be an alternative to fungicide applications prior to harvest.

Limits for acceptable fruit quality of plums in Norway were defined by Vangdal (1985). In the present work, the lower limit of soluble solids set to 12.5% was met by both categories of ripening in most experiments. For cv. Opal in 2015, both categories of ripeness were below the limit, and that was also the case for tree ripe- fruit of cv. Reeves in 2013. For cv. Reeves the acidity is generally low, and a lower content of soluble solids is acceptable (Vangdal et al., 2007a). Firmness, as determined by the DUROFEL instrument in 2013, was between 59 and 71, which was very close to or within the optimal maturity stage for picking, previously defined to be between 60 and 69 (Vangdal & Flatland, 2010). A recent study of firmness in highbush blueberry compared the DUROFEL and FirmTech 2 instruments for testing of fruit firmness and found significant correlations, also with tactile judgements (Moggia et al., 2022). No direct comparison between values of FirmTech 2 used in 2014 and 2015 and DUROFEL used in 2013 were done in the present experiment. The I_{AD}-index clearly documented the differences in maturity, indicating that it could be used to grade fruit at packaging, as shown for peach (Spadoni et al., 2016).

Five cultivars were included in the experiments, and for four of them there was a clear difference in postharvest fungal decay between the two ripening categories, but not for cv. Reeves. In a previous description of cv. Reeves in Norway, it was stated that it has low susceptibility to fungal decay and a long shelf life (Vangdal et al., 2007a), and this may thus explain the insignificant difference between the two maturity groups.

All diseases found on the fruit postharvest had higher incidence on the more mature fruit in one or more of the single experiments. Similar results were reported for brown rot on peach (Spadoni et al., 2016), but it has not been documented before for grey mould, blue mould, and Mucor rot. Both blue mould and Mucor rot are typical postharvest diseases (Michailides & Spotts, 1990; Snowdon, 1990), and in the present experiments the minor increase in ripeness for the more mature fruit clearly promoted both diseases. Injuries and wounds of the fruit at time of harvest promotes postharvest decay of both blue mould and Mucor rot (Michailides & Spotts, 1990; Snowdon, 1990). Incidence of smaller wounds, such as cuticular fractures, is higher on more ripe fruit since they are related to the rapid cell enlargement prior to harvest, as documented in sweet cherry (Knoche et al., 2001). In sweet cherry fruit, such fractures facilitated development of both *B. cinerea* and *M. laxa* postharvest (Børve et al., 2000).

Although the fruit of the more-mature category developed two to 10 times more decay than the less-mature fruit during a simulated sales period, all were categorized as harvested at optimal time. The present experiments show that what is considered optimal range in maturity should be more carefully judged at time of harvest and packaging. Distinguishing fruit in two or more ripening categories, may be an economically viable effort to ensure high quality fruit on the market. The present experiment documents two alternatives to synthetic fungicides against postharvest fruit rot in plum, a combination of preharvest foliar calcium applications and maturity grading.

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Data Availability Experimental data is available from the corresponding author.

Declarations

Ethics approval This article does not contain any studies with human participation or animals performed by any of the authors.

Conflict of interest The authors declare that no known conflicts of interest exist.

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