Pear

Paul M. Chen
Chen is with the Mid-Columbia Agricultural Research and Extension Center, Oregon State University, Hood River, OR

Scientific Name and Introduction

Pyrus communis L., the pear, is a member of the family Rosaceae. The fleshy part of pear fruit consists of the fused base of the calyx (sepals), corolla (petals), and stamens, which are interpreted by one school of anatomists as being the “receptacle.” Therefore, pears are also a pome fruit (Hulme and Rhodes 1971). Commercial pear production on the Pacific Coast is largely confined to nine districts including the Wenatchee and Yakima Valley areas in central Washington, the Hood River Valley in north central Oregon, and the Rogue River Valley around Medford in southern Oregon. In California, production is mainly in the foothill district of Eldorado, Placer, and Nevada counties; the Sacramento River district; the coast district north of San Francisco Bay known as the Santa Clara Valley district; and the southern California acreage mostly in the Antelope Valley in Los Angeles County (Childers 1949).

Pears rank third among the most important tree fruits grown in the world and fourth among all fruits for which statistics are available (Childers 1949). All important pear varieties grown in the United States belong to the European species, and commercial pear production is confined to six main varieties—‘Bartlett,’ ‘Beurré d’Anjou,’ ‘Beurré Bosc,’ ‘Beurré Hardy,’ ‘Doyenne’ du Comice,’ and ‘Seckel.’ Other minor varieties include ‘Winter Nelis,’ ‘El Dorado,’ ‘Kieffer,’ and ‘Packham’s Triumph.’

Quality Characteristics and Criteria

A properly ripened pear is buttery with juicy texture and the aroma and taste distinct to each cultivar. Pear fruit require a period of cold storage at -1 °C (30 °F) to induce normal ripening and develop high dessert quality upon ripening. When pear fruit meet the chilling requirement after a period of cold storage, they should be ripened at 20 °C (68 °F) in air for 4 to 7 days depending on the variety for the development of high dessert quality.

Horticultural Maturity Indices

Pear fruit are capable of developing good dessert quality upon ripening only if they are harvested at proper maturity. Pear fruit harvested at improper maturity are more susceptible to physiological disorders and have a shorter storage life. Immature pear fruit are more susceptible to superficial scald, shriveling, and friction discoloration, while overmature fruit tend to have higher incidence of core breakdown and CO_2 injury (Hansen and Mellenthin 1962, Fidler et al. 1973, Mellenthin and Wang 1974).

One of the most satisfactory and easiest ways of determining proper harvest maturity is to measure fruit firmness. A pressure test using a penetrometer on the pear surface gives an indication of flesh firmness. Firmness decreases with maturation. Different varieties have different firmness at maturity. Recommended ranges of firmness for harvesting different pear varieties as measured using a 8-mm plunger tip are as follows (Williams et al. 1978, Hansen and Mellenthin 1979):

	N
‘d’Anjou’	57.8 to 66.7
‘Bartlett’	66.7 to 84.3
‘Bosc’	62.7 to 71.6
‘Comice’	49.0 to 57.8
‘Hardy’	41.2 to 49.0
‘Kiefer’	52.9 to 66.7
‘Seckel’	57.8 to 66.7
‘Packham’	57.8 to 66.7
‘El Dorado’	57.8 to 66.7
‘Winter Nelis’	57.8 to 66.7

(1 N = 0.225 lb-force)

Heat units accumulated during the 9 weeks following full bloom provide an accurate prediction of maturity and harvest date. The equation (for Fahrenheit) can be expressed as—

Daily Heat Unit = [(Maximum Temp. + Minimum Temp.)/2] - 45

Heat units accumulated during the 9 weeks following full bloom have been developed at the Mid-Columbia Agricultural Research and Extension Center to provide an accurate prediction of the commercial harvest date for ‘d’Anjou’ and ‘Bartlett’ pear cultivars. The 50-yr record (1944 to 1994) at this Center has shown that correlation coefficients between the number of days from full bloom (DFFB) until harvest and the accumulated heat units (AHU) are -0.9213 for ‘d’Anjou’ pears and -0.8300 for ‘Bartlett’ pears. The linear equations between DFFB and AHU are—

‘d’Anjou’	DFFB = 177.5472 - 0.0481 × AHU
‘Bartlett’	DFFB = 147.5377 - 0.0353 × AHU

In Oregon’s Hood River Valley district, the entire pear-producing area covers elevations between 500 ft (152 m) and 2,000 ft (610 m). The dates of full bloom or the dates of first commercial harvest between the lower and higher elevations could be as much as 3 weeks apart. Predictive models for the harvest maturity of ‘d’Anjou’ and ‘Bartlett’ pears grown in 14 orchards representing the entire Hood River Valley district have been developed (Varga and Chen 1995). Other predictive methods such as days from full bloom, SSC, and starch-iodine test are quite variable from season to season and have not been adopted for routine practice by the pear industry.

Grades, Sizes, and Packaging

Grades include Extra Fancy, U.S. No. 1, Fancy, and Unclassified (or Third Grade) for all winter pear cultivars, and U.S. No. 1 and Fancy for ‘Bartlett.’ Grading is based primarily on external appearance. Size categories are 50, 60, 70, 80, 90, 100, 110, 120, 135, 150, 165, and 180 fruit per standard 20-kg box.

Precooling Conditions

Rapid removal of field heat and prompt cooling of harvested pears are essential for long-term storage. During the pull-down period, room temperatures of -3.5 to -2.0 °C (26 to 28 °F) can be used, but the environment should be raised to -1 °C (30 °F) as the fruit temperatures approach this temperature (Hansen and Mellenthin 1979). Delay in cooling shortens storage life. It has been suggested that the core temperature should be reduced to near the holding temperature in 4 days (Porritt 1965). When pears are packed in cartons before cooling, cartons should be stacked to provide exposure of the sides to airflow (Sainsbury and Schomer 1957).

Optimum Storage Conditions

Pears are very sensitive to temperature. The storage life of 'd'Anjou' and 'Bartlett' pears has been reported to be 35 to 40% longer at -1 °C (30 °F) than at 0 °C (32 °F) (Porritt 1964). Most pears in the Pacific Northwest are stored at -1 °C (30 °F) with RH of 90 to 94% (Hansen and Mellenthin 1979). Many operators of pear storage rooms use thermocouples in the air and in fruit to determine temperatures at selected areas in the storage. Precise temperature control is needed to prevent freezing when pears are stored at these low temperatures (Hartman 1931). Intermediate temperatures of 2.5 to 10 °C (37 to 50 °F) are harmful to some pear cultivars. 'Bartlett' pears stored at this temperature have dry texture and inferior flavor (Porritt 1964). Pears lose moisture rapidly; hence, it is advisable to hold RH at >90%. Polyethylene liners are effective in controlling moisture loss.

Controlled Atmosphere (CA) Considerations

CA storage has been used successfully to extend the storage life of pears and to maintain greater capacity for ripening. The optimum and safe CA for commercial use is 2 to 2.5% O_2 and 0.8 to 1% CO_2 (Hansen and Mellenthin 1979). Use of short-term high-CO_2 treatment improves keeping quality of 'd'Anjou' pears (Wang and Mellenthin 1975). Treatment with 12% CO_2 for 2 weeks immediately after harvest has a beneficial effect on retention of ripening capacity. Keeping 'd'Anjou' pears in a low-O_2 atmosphere (1.0%) with $\leq$0.1% CO_2 can also maintain higher dessert quality and reduce incidence of superficial scald after long-term cold storage (Hansen 1957, Mellenthin et al 1980).

Pear Ripening in Storage

Most pear cultivars require a period of cold storage before they will ripen normally at room temperature (Leblond and Ularic 1973, Drouet and Hartmann 1979, Blankenship and Richardson 1985, Morin et al. 1985, Knee 1987). Most cultivars do not soften appreciably during cold storage; hence, they require a period of ripening at warm temperature to develop good flavor and texture for eating. The best ripening temperature after storage is about 15 to 21 °C (59 to 70 ºF). Higher temperatures may result in poor quality or decay. Most cultivars fail to soften at 30 °C (86 ºF). It is generally recognized that ethylene induces ripening.

A striking characteristic of climacteric fruits is their autocatalytic ethylene production; that is to say, ethylene stimulates its own synthesis (Pech et al. 1994). During storage at -1 °C (30 °F), 1-aminocyclopropane-1-carboxylic acid (ACC; the immediate ethylene precursor) starts to accumulate; as a consequence, pear fruit begin to produce ethylene and ripen normally upon exposure to room temperature. Exposure of pear fruit to a storage temperature of -1 to 0 °C (30 to 32 °F) stimulates synthesis of ACC and ethylene because low temperature induces biosynthesis of ACC oxidase and ACC synthase (Blankenship and Richardson 1985, Wang et al. 1985, Leliévre at al. 1997, Agar et al. 2000). The duration of chilling required for proper ripening is cultivar-dependent (Wang et al. 1985) and varies with storage temperature (Sfakiotakis and Dilley 1974, Gerasopoulos and Richardson 1995). Storage duration at -1 °C (30 °F), which is required to induce normal ripening of pear fruit, is 2 to 4 weeks for ‘Bartlett’ (Puig et al. 1996, Agar et al. 1999), 2 to 3 weeks for ‘Bosc’ (Chen et al. 1982), and 7 to 8 weeks for ‘d’Anjou’ (Chen et al. 1982).

Exogenous ethylene, at 100 µL L^{-1}, has been used commercially to precondition underchilled ‘Bartlett’ and ‘d’Anjou’ pears at 20 °C (68 °F) for 2 to 3 days before shipment. Preconditioned pear fruit are capable of ripening normally and uniformly upon reaching the retail markets or for the canning process (Chen et al. 1996, Puig et al. 1996, Agar et al. 1999, 2000).

Ethylene Production and Sensitivity

Ethylene production rates are low at harvest: <0.1 µL kg^{-1} h^{-1}; but rates gradually increase during air storage at -1.1°C (30 °F). After 3 mo of air storage at -1.1 °C (30 °F) and 1 day at 20 °C (68 °F), ethylene production of ‘d’Anjou’ was 0.5 µL kg^{-1} h^{-1}; of ‘Bosc,’ 30 µL kg^{-1} h^{-1}; and of ‘Comice,’ 30 µL kg^{-1} h^{-1}.

Most pear cultivars will exhibit climacteric-like ethylene production during the ripening period at 20 °C (68 °F) when optimally mature fruit have satisfied their chilling requirement at -1.1 °C (30 °F). The chilling requirement of optimally mature pears stored at -1.1 °C (30 °F) for induction of normal ripening capacity is about 60 days for ‘d’Anjou,’ 30 days for ‘Bosc,’ 30 days for ‘Comice,’ and 15 days for ‘Bartlett.’ The magnitude of ethylene production at the climacteric-like peak is 10 to 20 µL kg^{-1} h^{-1} for ‘d’Anjou,’ 40 to 80 µL kg^{-1} h^{-1} for ‘Bosc,’ 80 to 200 µL kg^{-1} h^{-1} for ‘Bartlett,’ and 60 to 80 µL kg^{-1} h^{-1} for ‘Comice.’

Unripe pear fruit are somewhat sensitive to ethylene, depending on the cultivar. ‘Bartlett’ pears are most sensitive to ethylene, ‘Bosc’ and ‘Comice’ fruit are moderately sensitive, and ‘d’Anjou’ fruit are least sensitive to ethylene for induction of ripening. Nevertheless, it is best to avoid storing pear fruit near ripe fruit or other fresh produce that produces appreciable levels of ethylene. Preconditioning of pear fruit with 100 µL L^{-1} ethylene at 20 °C (68 °F) for 72, 48, or 24 h will induce ripening within 3 to 6 days, depending on the cultivar (Wang and Mellenthin 1972, Chen et al. 1982, Elgar et. al. 1997).

Respiration Rates

	‘d’Anjou’						*‘Bartlett’*				
Tempu-	Days in Storage						Days in Storage				
ature	1	25	50	100	150	200	1	10	20	90	120
°C	mg CO_2 kg^{-1} h^{-1}										
-2	5.0	2.0	2.0	2.3	2.4	2.7	—	1.5	2.2	3.2	3.8
-1	5.0	2.0	2.0	2.4	2.5	2.8	—	2.2	2.4	3.6	4.2

0	5.0	2.4	2.5	3.2	4.1	4.5	—	2.5	2.6	5.6	5.9
2	5.0	3.1	3.6	5.1	—	—	—	3.2	4.5	—	—
10	9.0	6.0	7.0	—	—	—	16.0	8.1	24.0	—	—
21	17.0	7.0	7.0	—	—	—	16.0	38.0	—	—	—

To get mL CO_2 kg^{-1} h^{-1}, divide the mg kg^{-1} h^{-1} rate by 2.0 at 0 °C (32 °F), 1.9 at 10 °C (50 °F), and 1.8 at 20 °C (68 °F). To calculate heat production, multiply mg kg^{-1} h^{-1} by 220 to get BTU ton^{-1} day^{-1} or by 61 to get kcal $tonne^{-1}$ day^{-1}.

Physiological Disorders

Superficial scald, also called storage scald, is a cosmetic condition of surface browning affecting only a few layers of cells beneath the skin. Eating quality of fruit is not affected. Frequently, fruit appear normal after several months in cold storage but then develop scald symptoms after a few days at room temperature. The unpleasant brown appearance makes fruit difficult to market.

Superficial scald affects ‘d’Anjou’ pears and other pear cultivars. The cause of superficial scald is conjugated trienes, the oxidative products of the naturally occurring terpene α-farnesene, which are toxic to the epidermal and endodermic cells of the fruit peel (Chen et al. 1990b). Factors that usually increase the severity of the disorder include immaturity, high fruit nitrogen, low fruit calcium, warm preharvest weather, delayed cold storage, high storage temperatures, and high RH during cold storage.

Conventional control method: The primary method of controlling superficial scald on ‘d’Anjou’ pears at present is a postharvest treatment of ethoxyquin, an antioxidant (Hansen 1964, Hansen and Mellenthin 1967, 1979). Ethoxyquin is recommended at a concentration of 2,700 µL L^{-1}, which can be applied to the fruit either as a drench, as a line spray, or by impregnating it into paper wraps (Hansen and Mellenthin 1979). Drenching fruit is done as soon as possible after harvest, usually no later than 2 days. Unfortunately, this treatment often causes considerable phytotoxicity when the ethoxyquin solution becomes more concentrated at contact points between fruit or between fruit and wooden bins. Fruit at these contact points develop pinkish (or blackened) ring markings during storage (Porritt et al. 1982), and the injured fruit become unmarketable. Ethoxyquin treatment as a line spray or a paper wrap is carried out during commercial packing. Because it usually takes about 3 mo to pack all fruit stored in air, fruit may receive ethoxyquin protection as early as 1 week after harvest or as late as 3 mo after storage using either of these methods. Though neither method causes any phytotoxicity to fruit, delay in ethoxyquin application has resulted in significant incidence of scald disorder at terminal markets. Current recommended ethoxyquin treatments are inadequate.

Split application of ethoxyquin control method: Drenching ‘d’Anjou’ fruit with 1,000 µL L^{-1} ethoxyquin within 2 days after harvest controlled scald development for 4 mo in air storage without causing phytotoxicity to fruit. Drenching fruit with 1,000 µL L^{-1} ethoxyquin within 2 days after harvest plus an additional line spray of 1,700 µL L^{-1} ethoxyquin within 3 mo of harvest controlled scald development for 5 mo in air storage

(Chen et al. 1990a).

Nonchemical control method: A short-term (3- to 4-mo) CA storage of ‘d’Anjou’ pears at -1 ºC in 0.8% O_2 and <0.1% CO_2 (denoted as low O_2) effectively controls development of superficial scald without inducing black speck and pithy brown core (Chen and Varga 1997a, 1997b). Fruit stored in a short-term low-O_2 regime remain free from scald after 8 weeks in air at -1 ºC. These fruit can be safely packed without antioxidant treatment and marketed after 2 mo of air storage.

Combined ethoxyquin/CA control method (Chen and Varga 1997a): For ‘d’Anjou’ fruit destined for mid-term (5- to 6-mo) or long-term (7- to 8-mo) CA storage, a prestorage drench of fruit with 1,000 µL L^{-1} ethoxyquin within 2 days after harvest was necessary in order to control superficial scald disorder. The concentrations of O_2 and CO_2 in CA storage must be kept at 1.5% and <0.5%, respectively, throughout the entire storage period to minimize development of black speck and pithy brown core. An alternative method would be to store field-run ‘d’Anjou’ pears in low O_2 (0.8% O_2 and <0.03% CO_2) at -1 °C (30 °F) for 90 days until qualified. Low-O_2 stored fruit can be either presized or packed with in-line spray of 2,700 µL L^{-1} ethoxyquin within 2 weeks after being returned to air storage. Treated fruit can be further stored in regular CA storage (2% O_2 and 1% CO_2) for another 3 to 4 mo at -1 °C (30 °F) for late season marketing.

Pithy brown core (PBC) affects ‘d’Anjou’ pears stored in either sealed polyethylene box liners or CA storage with elevated CO_2. It is characterized by pithy, brown areas in the core region of the fruit. It may be restricted to brown flecks between the carpels, or it may encompass the entire core and extend into the surrounding flesh. In some instances, the tissues collapse, producing cavities. The affected tissues are dry and pithy, in contrast to the soft, watery texture resulting from core breakdown. The disorder is associated with high CO_2 in atmospheres of sealed box liners or CA storage and is considered to be a form of CO_2 injury. It is aggravated by the combination of low O_2 and high CO_2 levels in CA storage. Susceptibility to PBC increases with factors that induce fruit senescence, such as late harvesting, delayed storage, slow cooling, high storage temperatures, and extended CA storage (Hansen and Mellenthin 1962). Fruit from trees with low vigor and fruit grown in cool seasons are more susceptible to PBC (Hansen and Mellenthin 1962).

For fruit stored loose in bins—field-run fruit—CO_2 should be maintained at <0.03% when O_2 in CA storage is 0.8 to 1.0% (Chen and Varga 1997b). The maximum storage length of ‘d’Anjou’ fruit stored under low O_2 should be no more than 120 days. For fruit stored loose in bins, CO_2 should be maintained at <0.5% when O_2 in CA storage is 1.5 to 1.8%. The maximum storage time of fruit stored in the CA regime described above should be no longer than 8 mo. For fruit stored loose in bins, CO_2 should be maintained at <1.0% when O_2 in CA storage 2.0 to 2.5%. The maximum storage time of fruit stored in the CA regime described above should also be no longer than 8 mo (Chen and Varga 1997b).

For fruit stored in packed boxes, only the CA regime with 2.0 to 2.5% O_2 and <1.0% CO_2 gives minimal risk for ‘d’Anjou’ pears to develop PBC after prolonged CA storage (6 to 8 mo) (Chen and Varga 1997b).

Black speck (BS), or “skin speckling,” of ‘d’Anjou’ pears becomes an economic problem after prolonged CA storage. It has been observed frequently in commercial CA storage. It is a physiological disease and is suspected to be closely associated with PBC. Kupferman (1988) reported that BS could develop on ‘d’Anjou’ pears with or without PBC. Similarly to PBC, ‘d’Anjou’ fruit develop BS only in CA storage. The unbalanced O_2 :CO_2 ratio in CA storage must be an initial factor in causing skin injury of fruit. It was confirmed that BS was induced by ≤1.0% O_2 in CA storage for longer than 4 mo and was not affected by <1% CO_2 (Chen and Varga 1989). Each BS spot consists of several hundred epidermal cells discolored to dark brown. The distinct specks scatter randomly on the peel tissue and are not restricted to around the lenticels. It affects only five to six layers of hypodermal cells of the skin (Kupferman 1988, Chen and Varga 1989, Lee et al. 1990).

Since BS is associated with low O_2 (≤1%), a CA regime with O_2 at 1.5% or higher will alleviate the disorder after prolonged CA storage. For ‘d’Anjou’ pears, low-O_2 (0.8 to 1.0% O_2) storage should not exceed 120 days (Chen and Varga 1997b).

Black end of ‘d’Anjou’ pears begins with symptoms appearing when fruit are one-third to one-half full size. It is a protrusion of the calyx due to the retarded development of tissues around the calyx. As the disorder progresses, the calyx lobes turn black, the tissues surrounding the calyx opening become hard, and a brownish discoloration forms. This discoloration may appear first in separate spots, which later coalesce; or there may be a large area completely and uniformly discolored from the beginning. The final color of affected tissues is black, and cracks up to 3 cm in length may appear in the blackened area. The affected area is usually confined to approximately 1 to 2 cm around the calyx, but it may cover the entire lower half of fruit in severe cases. Discoloration usually does not extend deep into the flesh, sometimes only affecting the skin.

Black end is believed to be caused by water imbalance stemming from a restricted root system. Excessive subsoil moisture in spring damages feeder roots, inducing development of the disorder. Fruit grown on trees with Asian rootstocks (*Pyrus serotina* Rehder) are highly susceptible to black end. Fruit grown on trees with French rootstocks (*Pyrus communis* L.) are generally free from the disorder (Heppner 1928, Davis and Tufts 1932).

Core breakdown has been referred to in different investigations as “internal breakdown,” “core rot,” “brown heart,” and “mealy core.” As the names imply, this disorder of pears is characterized by the softening and browning of tissues in the region of the core. The breakdown may be closely confined to the core or may extend into the surrounding flesh. In the early stages, the affected tissues are soft and watery; they later become dark brown. The disorder is often associated with an external skin discoloration resembling senescent scald.

Overmature fruit are more susceptible to core breakdown in storage and in the market. Late-harvested pears are unable to slow their metabolic activities sufficiently for successful storage at -1 °C (30 ºF). Serious breakdown can occur in storage or after pears are removed to ripen at 20 °C (68 ºF). Late-harvested pears show an increase in CO_2 in the tissues around the core area until the onset of core breakdown. Such fruit produce an abnormally high amount of acetaldehyde until core breakdown is advanced. 'Bartlett,' 'Bosc,' and 'Comice' pears are highly susceptible to core breakdown, whereas 'd'Anjou' pears are somewhat resistant. Harvesting fruit at optimum maturity and rapidly precooling fruit before storage are essential to reduce core breakdown (Hartman 1925, Harley 1929).

Senescent scald occurs differently in various pears. Pears can be classified broadly into two groups based on their storage behavior. One group, including 'd'Anjou,' 'Winter Nelis,' 'Packham's Triumph,' and 'Hardy,' senesce very slowly in cold storage and generally do not lose their capacity for normal ripening at room temperature as a result of extended storage. These pears are subject to storage scald, called "Anjou scald" or "superficial scald." The other group of pears, which includes 'Bartlett,' 'Bosc,' 'Howell,' 'Comice,' 'Sierra,' and 'Flemish Beauty,' show a higher rate of senescence during cold storage; fruit lose their ability for normal ripening at room temperature after prolonged storage. As storage length is extended, fruit become yellow and ultimately develop a dark brown discoloration of the skin called "senescent scald." This may occur in cold storage or after fruit are removed from cold storage and subjected to higher temperatures. Fruit remain firm, but the skin sloughs off easily (Porritt et al. 1982).

Methods of treating senescent scald are similar to those used to reduce core breakdown disorder, with overmature fruit more susceptible in storage and in the market. Pears that are harvested late do not exhibit a decrease in metabolic activity necessary for storage at -1 °C (30 ºF). There are no control measures other than harvesting pears at optimum maturity, reducing the storage period, and improving postharvest handling with methods such as fast cooling of pears immediately after harvest and maintaining constant temperature at -1 °C (30 ºF) throughout storage (Porritt et al. 1982).

Postharvest Pathology

A detailed description of pear diseases and control measures can be found in "Compendium of Apple and Pear Diseases" (Jones and Aldwinckle 1990). The cause of postharvest decay in pear fruit is often difficult to identify through symptoms alone. Many decay pathogens do not sporulate on fruit in cold or CA storage. The only reliable method for identifying the cause of decay is to isolate and identify the causal agent. Isolations are easily accomplished by removing the fruit skin over the margin of a decayed area and plating some of the decayed flesh on potato-dextrose agar.

Fungi causing postharvest decay in pome fruits can be subdivided into two broad groups: those that cause primarily postharvest decay and those that also cause fruit decay in the field. Postharvest decay attributable to fungi in the latter group usually result from infections that occurred in the field but were quiescent or otherwise escaped notice at harvest. Control measures for these diseases are based on the protection of fruit from preharvest infections. Control measures broadly applicable to many postharvest diseases include both sanitation and harvesting, as well as handling methods that maintain the integrity of harvested fruit. Sanitation measures are especially important for reducing exposure of fruit to spores of wound pathogens, such as *Penicillium* and *Botrytis*. Harvesting and handling methods are important because wounded, bruised, or overmature fruit are more susceptible to many postharvest decay fungi. Rapid cooling after harvest reduces the incidence of decay in storage, because low temperatures reduce both the rate of fungal growth and fruit senescence. Low temperature prevents development of incipient infections by some fungi in storage, such as those causing white rot and brown rot.

Postharvest decay pathogens infecting pears in the field and causing symptoms in stored pears as a result of incipient or quiescent infections are *Botryosphaeria dothidea* (white rot), *B. obtusa* (black rot), *Glomerella cingulata* (bitter rot), *Monilinia fructicola* (brown rot), *M. fructigena* (brown rot), *M. laxa* (brown rot), and *Phytophthora cactorum* (phytophthora fruit rot).

Postharvest diseases commonly found in pears after storage are blue mold (*Penicillium* spp.), gray mold (*Botrytis cuberea* Per.), bull's-eye rot (*Pezicula malicorticis* [H. Jacks.] Nannf.), alternaria rot (*Alternaria alternata* [Fr.] Keissler), mucor rot (*Mucor piriformis* E. Fischer), side rot (*Phialophora malorum* [Kidd & Beaumont] McColloch), cladosporium rot (*Cladosporium herbarum* [Pers.] Link), coprinus rot (*Coprinus psychromorbidus* Redhead & Traquair), fisheye rot (*Butlerelfia eustacei* Weresub & Illman), pink rot (*Trichothecium roseum* [Pers.] Link), and rhizopus rot (*Rhizopus stolonifer* [Ehrenb.] Vuill.).

References

Agar, I.T., W.V. Biasi, and E.J. Mitcham. 1999. Exogenous ethylene accelerates ripening responses in 'Bartlett' pears regardless of maturity or growing region. Postharv. Biol. Technol. 17:67-68.

Agar, I.T., W.V. Biasi, and E.J. Mitcham. 2000. Cold storage duration influences ethylene biosynthesis and ripening of 'Bartlett' pears. HortScience 35:687-690.

Blankenship, S.M., and D.G. Richardson. 1985. Development of ethylene biosynthesis and ethylene induced ripening in 'd'Anjou' pears during the cold requirement for ripening. J. Amer. Soc. Hort. Sci. 110:520-523.

Chen, P.M., S.R. Drake, D.M. Varga, and L. Puig. 1996. Precondition of 'd'Anjou' pears for early marketing by ethylene treatment. J. Food Qual. 19:375-390.

Chen, P.M., D.G. Richardson, and W.M. Mellenthin. 1982. Differences in biochemical composition between 'Beurre d'Anjou' and 'Bosc' pears during fruit development and storage. J. Amer. Soc. Hort. Sci. 107:807-812.

Chen, P.M., and D.M. Varga. 1989. Black speck. A superficial disorder of 'd'Anjou' pears after prolonged CA storage. *In* J.K. Fellman, ed., 5th International Controlled Atmosphere Research Conference, vol 1, Wenatchee, WA, pp. 145-156.

Chen, P.M., and D.M. Varga. 1997a. CA regimes for control of superficial scald of 'd'Anjou' pears. *In* G. Kupferman, ed., 13th Annual Washington Tree Fruit Postharvest Conference, Wenatchee WA, pp, 17-26.

Chen, P. M., and D.M. Varga. 1997b. Determination of optimum controlled atmosphere regimes for the control of physiological disorders of 'd'Anjou' pears after short-term, mid-term or long-term storage. *In* E.J. Mitcham, ed., 7th International Controlled Atmosphere Research Conference, July 13-18, 1997, University of California, Davis, vol. 2, pp. 85-90. University of California, Davis CA.

Chen, P.M., D.M. Varga, E.A. Mielke, et al. 1990a. Control of superficial scald on 'd'Anjou' pears by ethoxyquin: effect of ethoxyquin concentration, time and method of application, and a combined effect with controlled atmosphere storage. J. Food Sci. 55:167-170.

Chen, P.M., D. Varga, E. Mielke, et al. 1990b. Control of superficial scald on 'd'Anjou' pears by ethoxyquin: oxidation of α-farnesene and its inhibition. J. Food Sci. 55:171-175, 180.

Childers, N.F. 1949. Pear and quince culture. *In* R.W. Gregory, ed., Fruit Science, Orchard and Small Fruit Management, pp. 248-273. J.B. Lippincott, New York, NY.

Davis, L.D., and W.P. Tufts. 1932. Black end and its occurrence in selected pear orchards. Proc. Amer. Soc. Hort. Sci. 28:634-638.

Drouet, A., and C. Hartmann. 1979. Ployribosomes from pear fruit. Plant Physiol. 64:1104-1108.

Elgar, H.J., C.B. Watkins, S.H. Murray, and F.A. Gunson. 1997. Quality of 'Buerre Bosc' and 'Doyenne du Comice' pears in relation to harvest date and storage period. Postharv. Biol. Technol. 10:29-37.

Fidler, J.G., B.G. Wilkinson, K.L. Edney, and R.O. Sharples. 1973. The Biology of Apple and Pear Storage. Commonwealth Agricultural Bureaux, Farnham Royal, U.K.

Gerasopoulos, D., and D.G. Richardson. 1995. Changes in fatty acids of 'd'Anjou' pears in relation to storage temperature and calcium. Acta Hort. 379:459-466.

Hansen, E. 1957. Reactions of anjou pears to carbon dioxide and oxygen content of the storage atmosphere. Proc. Amer. Soc. Hort. Sci. 69:110-115.

Hansen, E. 1964. Control of anjou pear scald improves market appeal and quality. Oreg. State Hort. Soc. Ann. Rpt. 56:29.

Hansen, E., and W.M. Mellenthin. 1962. Factors influencing susceptibility of pears to carbon dioxide injury. Proc. Amer. Soc. Hort. Sci. 80:146-153.

Hansen, E., and W.M. Mellenthin. 1967. Chemical control of superficial scald on Anjou pears. Proc. Amer. Soc. Hort. Sci. 91:860-864.

Hansen, E., and W.M. Mellenthin. 1979. Commercial handling and storage practices for winter pears. Spec. Rpt. 550, Oregon Agricultural Experiment Station, Corvallis, OR.

Harley, C.P. 1929. Relation of picking time to acetaldehyde content and core breakdown of 'Bartlett' pears. J. Agric. Res. 39:483-493.

Hartman, H. 1925. The control of core breakdown in pears. Bull. 216, Oregon State University Agricultural Experiment Station, Corvallis, OR.

Hartman, H. 1931. A peculiar freezing trouble of pears in cold storage. Bull. 282, Oregon State University Agricultural Experiment Station, Corvallis, OR.

Heppner, M.J. 1928. Pear black-end and its relation to different rootstocks. Proc. Amer. Soc. Hort. Sci. 24:139-142.

Hulme, A.C., and M.J.C. Rhodes. 1971. Pome fruits. *In* A.C. Hulme, ed., The Biochemistry of Fruits and Their Products, vol. 2, pp. 333-373. Academic Press, New York, NY.

Jones, A.L., and H.S. Aldwinckle, eds. 1990. Compendium of Apple and Pear Diseases. Amer. Phytopath. Soc. Press, St. Paul, MN.

Knee, M. 1987. Development of ethylene biosynthesis in pear fruit at -1 °C. J. Exp. Bot. 38:1724-1733.

Kupferman, E.M. 1988. Research on skin speckling and pithy brown core of ‘d’Anjou’ pears reported. Good Fruit Grower 39(16):17-18.

Leblond, C., and R. Ularich. 1973. Controle de l’evolution de la maturation par divers traitements theriques et gazeux chez la poire “Passe-Crassane.” Bull. Inst. Intl. Froid. 3:69-74.

Lee, S.P., P. Chen, T.H.H. Chen, et al. 1990. Differences of biochemical components between the skin tissues of normal and black-speckled ‘d’Anjou’ pears after prolonged low oxygen storage. J. Amer. Soc. Hort. Sci. 115:784-788.

Leliévre, J.M., L. Tichit, P. Dao, et al. 1997. Effects of chilling on the expression of ethylene biosynthetic genes in ‘Passe-Crassane’ pear (*Pyrus communis* L.) fruit. Plant Mol. Biol. 33:847-855.

Mellenthin, W.M., P.M. Chen, and S.B. Kelly. 1980. Low oxygen effects on dessert quality, scald prevention, and nitrogen metabolism of ‘d’Anjou’ pear fruit during long-term storage. J. Amer. Soc. Hort. Sci. 105:522-527.

Mellenthin, W.M., and C.Y. Wang. 1974. Friction discoloration of ‘d’Anjou’ pears in relation to fruit size, maturity, storage and polyphenoloxidase activities. HortScience 9:592-593.

Morin, F., C. Rigault, and C. Hartmann. 1985. Consequences d’un sejour au froid sur le metabolisme de l’ethylene au cours de la maturation de la poire Passe Crassane apres recolte. Physiol. Veg. 23:353-359.

Pech, J., C. Balagué, A. Latche, and M. Bouzayen. 1994. Postharvest physiology of climacteric fruits: recent developments in the biosynthesis and action of ethylene. Sci. Des Aliment. 14:3-15.

Porritt, S.W. 1964. The effect of temperature on postharvest physiology and storage-life of pears. Can. J. Plant Sci. 44:568-579.

Porritt, S.W. 1965. Effect of cooling rate on storage-life of pears. Can. J. Plant Sci. 45:90-97.

Porritt, S.W., M. Meheriuk, and P.D. Lidster. 1982. Postharvest disorders of apples and pears. Agric. Can. Pub. no. 1737/E.

Puig, L., D.M. Varga, P.M. Chen, and E.A. Mielke. 1996. Synchronizing ripening in individual 'Bartlett' pears with ethylene. HortTechnology 6:24-27.

Sainsbury, G.F., and H.A. Schomer. 1957. Influence of carton stacking patterns on pear cooling rates. Marketing Research Report 171, U.S. Department of Agriculture, Washington, DC.

Sfakiotakis, E.M., and D.R. Dilley. 1974. Induction of ethylene production in 'Bosc' pears by postharvest stress. HortScience 9:336-338.

Varga, D.M., and P.M. Chen. 1995. Predicting optimum maturity essential for pears. Good Fruit Grower 46:39-40.

Wang, C.Y., and W.M. Mellenthin. 1972. Induction period and threshold temperatures for premature ripening in 'Bartlett' pears. J. Amer. Soc. Hort. Sci. 97:557-560.

Wang, C.Y., and W.M. Mellenthin. 1975. Effect of short-term high CO_2 treatment on storage response of 'd'Anjou' pears. J. Amer. Soc. Hort. Sci. 100:492-495.

Wang, C.Y., C.E. Sams, and K.C. Gross. 1985. Ethylene, ACC, soluble polyuronide, and cell wall noncellulosic neutral sugar content in 'Eldorado' pears during cold storage and ripening. J. Amer. Soc. Hort. Sci. 110:687-691.

Williams, M.W., H.M. Couey, H. Moffitt, and D.L. Coyier. 1978. Pear Production. Agriculture Handbook 526, U.S. Department of Agriculture, Washington, DC.

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