Populations of *Botrytis cinerea* and *Penicillium* spp. on Pear Fruit, and in Orchards and Packinghouses, and Their Relationship to Postharvest Decay

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ABSTRACT

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The aims of this study were to examine the sources and population sizes of *Botrytis cinerea* and *Penicillium* spp. in 'd'Anjou' pear orchards, packinghouses, and storage, and to determine the relationship between population sizes and postharvest decay. Densities of *B. cinerea* ranged from nondetectable to 4.0 CFU/cm² on fruit, nondetectable to 3.1 CFU/liter in orchard air, and nondetectable to 1,167 CFU/g in orchard litter. The majority of packinghouse air and orchard soil samples collected yielded no *B. cinerea* inoculum. Densities of *Penicillium* spp. ranged from nondetectable to 2.7 CFU/cm² on pear fruit, nondetectable to 3.13 CFU/liter in orchard air, nondetectable to 11.8 CFU/liter in packingline air, nondetectable to 3.9 CFU/liter in cold-storage air, 38 to 431 CFU/g in orchard soil, and 131 to 1,128 CFU/g in orchard litter. The mean incidence of gray mold in stored d'Anjou pear fruit ranged from 0.7 to 10.7%. Incidence of blue mold ranged from 0 to 16.5%. Significant positive correlations were observed between decay and fruit surface populations of *B. cinerea* and *Penicillium* spp. In conclusion, inoculum levels of these important postharvest pathogens in orchard and packinghouse air, and orchard soil and litter, cannot be used as indicators of postharvest decay; whereas the inoculum level on fruit surfaces may be a useful predictor of decay.

Botrytis and *Penicillium* spp. are among the most commonly found plant pathogens and saprophytes (2,10), with *Botrytis cinerea* Pers.:Fr. and *Penicillium expansum* Link ex Thom. being responsible for a significant portion of postharvest losses incurred by the pear-packing industry of the Pacific Northwest (13,15,18,21). Levels of gray mold caused by *B. cinerea* and blue mold caused by *P. expansum* in stored 'd'Anjou' pears varies with year, grower, and often fruit lot. The availability of reliable models for predicting decay caused by these pathogens would be of great value to the industry. Fruit predicted as having a high incidence of decay could be sold first, whereas fruit predicted to have a low incidence of decay could be safely stored for longer periods.

Propagules of these decay fungi found in soil, plant litter, air (8,21), and packing-

house dump tank water (3,4,5,18,21) are potential sources of inoculum for postharvest decay. It is generally assumed that the initial inoculum of these decay-causing fungi originates in the orchard (8) and is dispersed as dry or wet conidia that could land on dry fruit, or fruit wet with dew or rain. Spotts and Cervantes (23), using a settling tower (17), inoculated dry and wet d'Anjou pear fruit with dry conidia of *B. cinerea* and *P. expansum*. They found a highly significant linear relationship between decay incidence and conidial concentration. Although inoculum densities of these two pathogens have been quantified in the packinghouse environment (18,21), there is little information available on inoculum levels in the pear orchard environment, including air, soil, and litter, and their relationship to decay.

The objectives of this study were to determine the density of *B. cinerea* and *Penicillium* spp. populations in both the pear orchard and packinghouse environments, to examine the incidence of postharvest decay caused by of *B. cinerea* and *Penicillium* spp. on d'Anjou pears, and to determine the relationships between the various sources of inoculum and incidence of postharvest decay.

MATERIALS AND METHODS

Populations on the fruit surface. From 1994 to 1998, d'Anjou pear fruit were collected about 1 week before harvest in

several orchards in the Mid-Columbia region of Oregon and Washington. In 1999, fruit were collected 24 days before harvest. The number of fruit sampled per orchard was 6 (1996 and 1997), 10 (1998), 12 (1994 and 1995), or 50 (1999). Fruit were handled carefully by the pedicel to avoid disturbing the surface. Each fruit was weighed, then immersed in sterile distilled water containing 0.1% Tween 80. Fruit were shaken on a rotary shaker at 150 rpm for 5 min (10 min in 1999), then sonicated (L & R model T-14; L & R Manufacturing Co., Kearny, NJ) for 5 min (10 min in 1999). In 1999, five fruit per tree were collected from 10 replicate trees, and all fruit from each tree were successively immersed in the same wash water. A 0.20- or 0.40-ml aliquot of the wash water was placed on duplicate petri dishes of *Botrytis*-selective Kerssies medium (11) (1994 to 1997) or acidified potato dextrose agar (APDA) (1998 and 1999). The decision to change to APDA was made in 1998 in order to include *Penicillium* spp. in our observations. Plates were incubated at 22°C for 1 (APDA) or 2 (Kerssies) weeks, after which time all fungal colonies were examined to determine their identity. Surface area of each fruit was estimated from a regression equation (6) with fresh weight as the independent variable. Population densities were calculated from plate counts, dilution factors, and fruit area, and expressed as CFU per unit surface area of fruit.

Airborne population density. Air was sampled 1 week before harvest in 1996 to 1998 and 24 days before harvest in 1999 in several orchards in the Mid-Columbia region of Oregon and Washington. A portable air sampler for agar plates (Burkard Manufacturing Co., Ltd., Hertfordshire, UK) was used to sample the air. Orchard air was sampled between 8:00 and 10:00 A.M. during windless periods. Air samples from the packingline area of commercial packinghouses were collected during the 1996 to 2000 packing seasons while the lines were operational. In orchards and packingline areas, 10 liters of air (20 liters in orchards in 1999) were impinged onto a petri dish containing 27 ml of APDA. In cold-storage rooms, 20 liters of air were sampled. Three (1996 to 1998) and five (1999) replicate samples were collected in each orchard and three samples in each packinghouse. Plates were incubated at

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22°C and examined under a stereomicroscope at ×12 after an incubation period of 2 to 4 days to determine colony identities and numbers.

Populations in orchard soil and litter.

Loose surface litter (consisting of detritus, and excluding living plant material) and soil in the top 5 cm were collected 1 week before harvest in 1996 to 1998 and 24 days before harvest in 1999 from the north, south, east, and west sides of the drip line of three trees in each orchard. Litter samples were kept separate from soil samples. The 12 soil or litter samples from each orchard were pooled and mixed. A 100-g subsample was removed and blended for 30 s with 200 ml of sterile distilled water. After 2 min of settling, 100 µl of supernatant was spread on each of three

petri dishes containing Kerssies medium (1996 and 1997) or APDA (1998 and 1999). Dishes were kept at 22°C and all fungal colonies counted after 5 to 7 days for APDA and 14 days for Kerssies. In 1999, soil and litter samples were collected from around each of 10 trees and processed separately.

Decay of fruit in cold storage. Fruit were harvested about 1 week before commercial harvest. In 1996 and 1997, harvested fruit from each orchard were placed into 10 wood boxes, each containing about 18 kg of fruit. In 1998, 20 boxes of fruit were harvested from each orchard. Boxes were lined with perforated polyethylene bags, and fruit were stored in air at -1°C. Fruit were evaluated for incidence of blue and gray mold after 3, 6, and 8 months.

After each evaluation, visibly decayed fruit were removed to prevent secondary spread. After the 8-month evaluation, fruit were ripened at 20°C for 7 days and evaluated again. Decay in all evaluations was summed and the total percent of decayed fruit was calculated.

Data analysis. The relationship between population levels of *B. cinerea* and *Penicillium* spp. and decay in storage caused by these two pathogens were examined. Correlation coefficients were determined based on simple linear relationships between fungal populations on fruit surfaces, in orchard and packinghouse air, and in orchard soil and litter, and between fungal populations and incidence of post-harvest decay after storage.

RESULTS

Populations on the fruit surface. The average fruit surface area was 150 cm². Considerable variability in propagule density was observed on surfaces of harvested fruit. Density of *B. cinerea* was 4.0 ± 1.1 and 0.6 ± 0.3 CFU/cm² in 1994 and 1995, respectively. Density of *B. cinerea* ranged from nondetectable to 1.4 CFU/cm² on fruit collected prior to commercial harvests in 1996 through 1999 (Table 1). Population density of *Penicillium* spp. on the surface of pear fruit prior to commercial harvests of 1998 and 1999 ranged from nondetectable to 2.7 CFU/cm² (Table 1).

Airborne population density. Propagule densities in the air of d'Anjou pear orchards prior to commercial harvest in 1996 through 1999 ranged from nondetectable to 3.1 CFU/liter for *B. cinerea*, and from nondetectable to 3.13 CFU/liter for *Penicillium* spp. (Table 2). Population densities of *Penicillium* spp. in air collected near the packingline of commercial packinghouses during 1996 to 2000 ranged from 0.1 to 11.8 CFU/liter (Table 3). The

Table 1. Populations of *Botrytis cinerea* and *Penicillium* spp. on the surface of 'd'Anjou' pear fruit 7 or 24 days before commercial harvest^a

Orchard	Population (CFU/cm ²) ^b					
	<i>Botrytis cinerea</i>				<i>Penicillium</i> spp.	
	1996	1997	1998	1999	1998	1999
1	0.2 ± 0.2	...	0.0 ± 0.0	...	2.7 ± 1.5	...
2	0.0 ± 0.0	0.2 ± 0.2	0.2 ± 0.2	1.3 ± 0.4	0.0 ± 0.0	0.9 ± 0.7
3	0.8 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	...	0.3 ± 0.2	...
4	0.8 ± 0.6	0.2 ± 0.2	0.0 ± 0.0	...	0.2 ± 0.2	...
5	0.4 ± 0.3	0.2 ± 0.2	0.0 ± 0.0	...	0.0 ± 0.0	...
6	1.4 ± 0.9	1.0 ± 0.5	0.0 ± 0.0	...	0.0 ± 0.0	...
7	0.3 ± 0.3	0.6 ± 0.4	0.0 ± 0.0	...	0.0 ± 0.0	...
8	0.5 ± 0.5	0.7 ± 0.3	...	...	...	...
9	0.0 ± 0.0	0.6 ± 0.4	...	...	...	...
10	0.3 ± 0.3	0.9 ± 0.5	...	...	...	...
11	0.3 ± 0.3	0.0 ± 0.0	...	...	...	...
12	0.0 ± 0.0	0.4 ± 0.2	...	...	...	...
13	0.2 ± 0.2	0.0 ± 0.0	...	...	...	...
14	0.7 ± 0.7	...	...	...	...	...
15	0.6 ± 0.4	...	...	...	...	...
16	0.2 ± 0.2	0.0 ± 0.0	...	...	...	...

^a Spores removed from fruit by combination of rotary shaking and sonication, then plated on acidified potato dextrose agar or Kerssies medium.

^b Mean ± standard error of the mean of 6 to 50 fruit. Fruit sampled 1 week before commercial harvest in 1996 to 1998, and 24 days before commercial harvest in 1999.

Table 2. Populations of *Botrytis cinerea* and *Penicillium* spp. in the air of 'd'Anjou' pear orchards 7 or 24 days before commercial harvest^a

Orchard	Population (CFU/liter of air) ^b						
	<i>Botrytis cinerea</i>				<i>Penicillium</i> spp.		
	1996	1997	1998	1999	1996	1998	1999
1	0.00 ± 0.00	...	...	...	0.00 ± 0.00	...	...
2	0.23 ± 0.15	3.10 ± 1.43	0.00 ± 0.00	0.12 ± 0.03	0.07 ± 0.07	0.57 ± 0.18	0.10 ± 0.03
3	0.17 ± 0.09	0.03 ± 0.03	0.07 ± 0.07	...	0.13 ± 0.03	1.13 ± 0.41	...
4	0.37 ± 0.07	0.00 ± 0.00	0.03 ± 0.03	...	0.10 ± 0.06	0.43 ± 0.23	...
5	0.23 ± 0.12	0.33 ± 0.19	0.07 ± 0.07	...	0.37 ± 0.09	0.80 ± 0.35	...
6	0.10 ± 0.06	0.00 ± 0.00	0.10 ± 0.10	...	0.33 ± 0.07	3.13 ± 0.45	...
7	0.03 ± 0.03	0.10 ± 0.06	0.10 ± 0.10	...	0.13 ± 0.03	0.80 ± 0.44	...
8	0.33 ± 0.15	0.20 ± 0.20	...	...	1.37 ± 0.03	...	...
9	0.07 ± 0.07	0.07 ± 0.03	...	...	0.00 ± 0.00	...	...
10	0.07 ± 0.07	0.00 ± 0.00	...	...	0.00 ± 0.00	...	...
11	0.17 ± 0.09	0.00 ± 0.00	...	...	0.03 ± 0.03	...	...
12	0.47 ± 0.19	1.47 ± 1.13	...	...	0.00 ± 0.00	...	...
13	0.00 ± 0.00	0.00 ± 0.00	...	...	0.03 ± 0.03	...	...
14	0.00 ± 0.00	...	...	...	0.00 ± 0.00	...	...
15	0.33 ± 0.09	...	...	...	0.03 ± 0.03	...	...
16	0.33 ± 0.07	0.17 ± 0.09	...	...	0.10 ± 0.06	...	...

^a Ten liters impinged onto each acidified potato dextrose agar plate (20 liters in 1999) with a Burkard portable air sampler for agar plates.

^b Mean ± standard error of the mean of three (1996 to 1998) or five (1999) samples. Air sampled 1 week before commercial harvest, 1996 to 1998, and 24 days before commercial harvest in 1999.

highest levels of *Penicillium* spp. were found in packingline air samples collected after January (Table 3). Density of *Penicillium* spp. in air samples collected

from the cold-storage facilities ranged from nondetectable to 3.9 CFU/liter, and the increase in population density of this pathogen that was observed in packingline

air samples after January was not observed in samples from cold-storage facilities (Table 3). *B. cinerea* rarely was found in air in the packinghouse or cold storage.

Populations in orchard soil and litter.

The majority of soil samples collected in commercial d'Anjou pear orchards before harvest yielded no *B. cinerea* although, in some orchards, populations ranged from 26 to 125 CFU/g of soil (Table 4). Population density of *B. cinerea* in litter samples collected in commercial d'Anjou pear orchards before harvest ranged from nondetectable to 1,167 CFU/g (Table 4). *Penicillium* spp. were found in all soil and litter samples collected in commercial d'Anjou pear orchards in 1998 and 1999. Mean inoculum density ranged from 38 to 431 CFU/g of soil and 131 to 1,128 CFU/g of litter (Table 4). Densities of *Penicillium* spp. in the soil were consistently lower than those in the litter (Table 4).

Decay of fruit in cold storage. The mean incidence of gray mold caused by *B. cinerea* in stored d'Anjou pear fruit ranged from 1.9 to 10.7% in 1996, 0.7 to 6.6% in 1997, and 0.9 to 10.1% in 1998 (Table 5). Incidence of blue mold caused by *P. expansum* in stored d'Anjou pear fruit from commercial orchards ranged from 0 to 8.2% in 1996, 0.5 to 16.5% in 1997, and 0 to 0.5% in 1998 (Table 5). Limited sporulation occurred on decayed fruit, and fruit were handled carefully to limit exposure of healthy fruit to additional inoculum. In this study, we cannot discount the possibility that fruit monitored for decay might have been exposed to additional inoculum during decay monitoring.

Relationships between population levels and postharvest decay. Significant positive correlations ($P < 0.05$) for *B. cinerea* were observed between decay and fruit surface populations in 1996 and 1998, but not in 1997 (Table 6). Many of the soil samples taken in the pear orchards contained no propagules of *B. cinerea*; consequently, we could not determine the rela-

Table 3. Populations of *Penicillium* spp. in packinghouse air

Date	House	Population (CFU/liter) ^a	
		Packingline	Cold storage
20 December 1996	1	0.7 ± 0.0	0.0 ± 0.0
20 December 1996	2	0.8 ± 0.1	0.1 ± 0.1
20 December 1996	3	3.4 ± 0.3	...
3 January 1997	4	0.8 ± 0.0	0.2 ± 0.1
28 January 1997	4	5.1 ± 0.1	1.9 ± 0.1
1 February 1997	1	0.3 ± 0.1	0.1 ± 0.1
1 February 1997	2	1.1 ± 0.3	0.0 ± 0.0
1 February 1997	4	8.1 ± 0.5	0.8 ± 0.2
14 February 1997	4	7.6 ± 0.1	1.4 ± 0.3
24 February 1997	4	9.7 ± 0.3	0.5 ± 0.2
29 January 1998	2	5.9 ± 1.3	0.8 ± 0.1
18 February 1998	4	8.0 ± 2.0	0.1 ± 0.0
3 March 1998	1	3.4 ± 0.4	0.2 ± 0.1
3 March 1998	3	5.8 ± 1.5	0.1 ± 0.1
21 April 1998	4	5.1 ± 0.3	0.6 ± 0.1
22 January 1999	1	0.8 ± 0.2	1.8 ± 1.1
	2	0.4 ± 0.3	1.8 ± 0.2
	3	0.2 ± 0.1	0.3 ± 0.1
	4	1.6 ± 0.2	3.1 ± 0.9
27 January 1999	4	4.6 ± 0.4	0.8 ± 0.1
28 January 1999	1	0.1 ± 0.0	0.0 ± 0.0
	2	0.2 ± 0.1	0.0 ± 0.0
	3	0.2 ± 0.2	0.2 ± 0.1
1 March 1999	4	6.2 ± 0.2	3.4 ± 0.8
7 March 1999	1	0.2 ± 0.1	0.4 ± 0.2
	3	0.1 ± 0.1	0.3 ± 0.2
16 March 1999	4	11.8 ± 0.6	2.2 ± 0.1
18 March 1999	1	0.3 ± 0.1	0.1 ± 0.1
	2	2.3 ± 0.6	0.9 ± 0.2
	3	1.4 ± 0.6	0.4 ± 0.3
22 March 1999	4	11.3 ± 1.9	3.9 ± 0.5
12 January 2000	4	1.6 ± 0.7	0.3 ± 0.1
13 January 2000	1	0.5 ± 0.1	0.1 ± 0.0
	2	2.1 ± 0.2	0.2 ± 0.1
	3	...	0.0 ± 0.0
26 January 2000	1	0.3 ± 0.1	0.0 ± 0.0
	2	0.6 ± 0.1	0.0 ± 0.0
	3	...	0.0 ± 0.0
1 February 2000	4	0.2 ± 0.1	0.1 ± 0.0
9 February 2000	1	7.9 ± 0.3	0.1 ± 0.0
	2	2.0 ± 0.3	0.2 ± 0.1
	3	...	0.0 ± 0.0
	4	6.5 ± 1.9	0.6 ± 0.4

^a Mean ± standard error of the mean of three samples.

Table 4. Populations of *Botrytis cinerea* and *Penicillium* spp. in soil and litter of 'd'Anjou' pear orchards 7 or 24 days before commercial harvest

Orchard	Population (CFU/g of dry soil or litter) ^a											
	<i>Botrytis cinerea</i>								<i>Penicillium</i> spp.			
	1996		1997		1998		1999		1998		1999	
	Soil	Litter	Soil	Litter	Soil	Litter	Soil	Litter	Soil	Litter	Soil	Litter
1	0 ± 0	172 ± 172	...	...	0 ± 0	16 ± 16	...	...	38 ± 38	131 ± 71	...	...
2	...	...	0 ± 0	0 ± 0	0 ± 0	16 ± 16	73 ± 12	253 ± 14	90 ± 26	371 ± 280	431 ± 117	584 ± 110
3	0 ± 0	0 ± 0	56 ± 47	214 ± 34	0 ± 0	16 ± 16	...	...	353 ± 185	726 ± 462	...	...
4	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	32 ± 32	...	...	56 ± 56	1,128 ± 206	...	...
5	...	...	0 ± 0	0 ± 0	0 ± 0	32 ± 32	...	...	217 ± 182	1,079 ± 304	...	...
6	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	47 ± 47	...	...	64 ± 64	483 ± 284	...	...
7	0 ± 0	181 ± 181	0 ± 0	111 ± 111	0 ± 0	50 ± 29	...	...	125 ± 66	712 ± 276	...	...
8	0 ± 0	0 ± 0	26 ± 26	183 ± 59	...	...	...	...	...	...	...	...
9	0 ± 0	0 ± 0	0 ± 0	0 ± 0	...	...	...	...	...	...	...	...
10	0 ± 0	0 ± 0	0 ± 0	691 ± 137	...	...	...	...	...	...	...	...
11	0 ± 0	0 ± 0	6 ± 6	1,167 ± 42	...	...	...	...	...	...	...	...
12	0 ± 0	0 ± 0	0 ± 0	180 ± 32	...	...	...	...	...	...	...	...
13	0 ± 0	0 ± 0	0 ± 0	257 ± 159	...	...	...	...	...	...	...	...
16	0 ± 0	0 ± 0	125 ± 45	468 ± 91	...	...	...	...	...	...	...	...

^a Mean ± standard error of the mean. Soil and litter sampled 1 week before commercial harvest in 1996 to 1998 and 24 days before commercial harvest in 1999.

tionship between soil populations and decay caused by this pathogen. The positive correlation between decay caused by *P. expansum* and the population of *Penicillium* spp. detected on fruit surfaces was significant ($P = 0.01$) in 1998 (Table 6).

DISCUSSION

The annual and locational variability in postharvest decay levels makes planning of storage and marketing of d'Anjou pear fruit difficult. Currently, levels of postharvest decay caused by *B. cinerea* and *P. expansum* cannot be predicted because no reliable prediction model exists. In this

study, we investigated whether inoculum source and size could be used to predict levels of decay in storage. We were not able to distinguish between species of *Penicillium* collected from the various sources of inoculum and, consequently, we have reported the results for *Penicillium* spp.

Considerable variability in propagule densities on fruit surfaces was observed in fruit collected before commercial harvest. It is assumed that weather (rain and wind) and orchard management activities cause dispersal of conidia from ground litter, leaves, and bark and deposition onto the

fruit. Spotts and Cervantes (23) showed that low inoculum concentrations (<10 CFU/cm²) of both *B. cinerea* and *P. expansum* on fruit surfaces can cause significant levels of decay in storage if the fruit is wounded. Injuries to pear fruit sustained during harvest and transit to packinghouses and handling in the packinghouse provide both these pathogens with ideal infection courts. The incorporation of fruit surface inoculum levels recorded in this study into regression equations obtained by Spotts and Cervantes (23) indicates that the inoculum levels should cause commercially unacceptable levels of gray and blue mold.

For inoculum deposited on the pear fruit surface to be effective, it must survive this relatively harsh environment. Spotts (20) found that 50% of conidia of *B. cinerea* survived for approximately 14 days in the orchard, whereas 50% of *P. expansum* conidia died after approximately 6 days. Consequently, conidia of these species landing on the pear surface earlier than 2 weeks before harvest are unlikely to contribute to decay unless they form latent infections. Direct penetration of a number of hosts by conidial germ tubes of *B. cinerea* has been described (26), and Rijkenberg et al. (16) found morphological evidence of latent infection of *B. cinerea* in tomato fruit. However, whether latent infections play a significant role in the epidemiology of *B. cinerea* and *P. expansum* on pear fruit seems unlikely in light of the results of Spotts (19), who found that both of these pathogens require a wound for infection.

Inoculum levels of *B. cinerea* have been measured in the air in strawberry and raspberry fields (9,14), with dispersal being related to weather. Propagule density in the air of d'Anjou pear orchards prior to commercial harvest ranged from nondetectable to 3.1 CFU/liter for *B. cinerea*, and from nondetectable to 3.13 CFU/liter for *Penicillium* spp. The regression equations of Spotts and Cervantes (23) show that densities of *B. cinerea* and *P. expansum* in air of less than 3 conidia/liter can cause significant levels of decay in storage. Consequently, inoculum levels detected in this study were sufficient to cause postharvest decay.

Population densities of *Penicillium* spp. in air collected near operating packinglines of commercial packinghouses ranged from 0.1 to 11.8 CFU/liter and samples collected after January each year showed higher levels of this pathogen. Spotts and Cervantes (21) noticed a similar increase in *Penicillium* spp. in both packinghouse air and dump water as the packing season progressed. They attributed this increase in population density to decaying fruit stored in bins that are passed through the dump tank water during packing operations. Air samples collected from the cold-storage facilities had lower levels of *Penicillium*

Table 5. Incidence of gray and blue mold in 'd'Anjou' pear fruit stored for 8 months at -1°C followed by a ripening period of 7 days at 20°C

Orchard	Decay incidence (%) ^a					
	Gray mold			Blue mold		
	1996	1997	1998	1996	1997	1998
1	1.9 ± 0.6	...	...	0.3 ± 0.1	...	...
2	8.0 ± 1.1	5.5 ± 1.0	10.1 ± 1.4	0.0 ± 0.0	1.6 ± 0.5	0.0 ± 0.0
3	4.1 ± 1.1	4.6 ± 1.3	1.8 ± 0.4	2.1 ± 0.5	3.2 ± 0.7	0.4 ± 0.2
4	7.9 ± 1.4	3.3 ± 0.8	2.1 ± 0.4	2.6 ± 0.7	5.0 ± 1.9	0.5 ± 0.2
5	6.8 ± 1.8	6.6 ± 1.3	0.9 ± 0.2	0.2 ± 0.2	3.3 ± 1.6	0.1 ± 0.1
6	10.7 ± 1.6	3.1 ± 0.8	3.1 ± 0.4	0.1 ± 0.1	2.3 ± 1.1	0.1 ± 0.1
7	7.2 ± 1.9	3.5 ± 0.6	7.2 ± 0.7	0.3 ± 0.2	0.5 ± 0.3	0.0 ± 0.0
8	3.2 ± 0.7	1.3 ± 0.6	...	1.4 ± 0.3	7.0 ± 1.9	...
9	3.9 ± 1.2	2.5 ± 0.6	...	1.4 ± 0.6	2.8 ± 1.0	...
10	6.0 ± 1.9	1.4 ± 0.3	...	5.7 ± 1.3	4.5 ± 1.6	...
11	4.3 ± 1.3	1.6 ± 0.5	...	0.9 ± 0.4	11.3 ± 2.1	...
12	3.0 ± 1.2	0.8 ± 0.3	...	5.4 ± 1.3	5.0 ± 0.9	...
13	3.6 ± 1.3	0.7 ± 0.2	...	3.8 ± 1.3	4.0 ± 1.8	...
16	3.6 ± 1.1	1.8 ± 0.6	...	8.2 ± 1.7	16.5 ± 2.0	...

^a Values are mean ± standard error of the mean of 10 (1996, 1997) or 20 (1998) boxes of fruit.

Table 6. Linear correlations between populations of *Botrytis cinerea* and *Penicillium* spp. on the surface of 'd'Anjou' pear fruit, in orchard and packinghouse air and orchard soil and litter, to incidence of postharvest decay caused by these pathogens in storage

Pathogen	Comparison	Year	n ^a	Correlation coefficient	P value
<i>Botrytis</i>	Surface versus litter	1996	12	0.191	0.55
<i>Botrytis</i>	Surface versus litter	1997	13	0.216	0.48
<i>Botrytis</i>	Surface versus litter	1998	7	0.418	0.35
<i>Botrytis</i>	Surface versus air	1996	16	0.048	0.86
<i>Botrytis</i>	Surface versus air	1997	13	0.131	0.67
<i>Botrytis</i>	Surface versus air	1998	6	0.761	0.08
<i>Botrytis</i>	Litter versus air	1996	12	0.467	0.13
<i>Botrytis</i>	Litter versus air	1997	13	0.264	0.38
<i>Botrytis</i>	Litter versus air	1998	6	0.733	0.10
<i>Botrytis</i>	Decay versus air	1996	14	0.048	0.87
<i>Botrytis</i>	Decay versus air	1997	13	0.311	0.30
<i>Botrytis</i>	Decay versus air	1998	6	0.377	0.46
<i>Botrytis</i>	Decay versus litter	1996	12	0.062	0.85
<i>Botrytis</i>	Decay versus litter	1997	13	0.474	0.10
<i>Botrytis</i>	Decay versus litter	1998	6	0.795	0.89
<i>Botrytis</i>	Decay versus surface	1996	14	0.584	0.03
<i>Botrytis</i>	Decay versus surface	1997	13	0.162	0.60
<i>Botrytis</i>	Decay versus surface	1998	6	0.795	0.05
<i>Penicillium</i>	Surface versus soil	1998	7	0.312	0.50
<i>Penicillium</i>	Surface versus litter	1998	7	0.606	0.15
<i>Penicillium</i>	Surface versus air	1998	6	0.22	0.67
<i>Penicillium</i>	Soil versus air	1998	6	0.15	0.78
<i>Penicillium</i>	Litter versus air	1998	6	0.445	0.38
<i>Penicillium</i>	Soil versus litter	1998	7	0.356	0.43
<i>Penicillium</i>	Decay versus air	1996	14	0.218	0.45
<i>Penicillium</i>	Decay versus air	1998	6	0.185	0.73
<i>Penicillium</i>	Decay versus soil	1998	6	0.255	0.63
<i>Penicillium</i>	Decay versus litter	1998	6	0.568	0.24
<i>Penicillium</i>	Decay versus surface	1998	6	0.904	0.01

^a Number of data pairs used to calculate each correlation coefficient.

spp. (ranging from nondetectable to 3.9 CFU/liter) than packingline air samples, and the population density increases of this pathogen observed in packingline air samples were not observed. These levels reflect the relatively undisturbed environment of the cold-storage facilities. Once the fruit is taken out of cold storage and processed for packing, *Penicillium* spp. inoculum probably is dispersed into the air or dump tank water.

Inoculum of *B. cinerea* seldom was found in soil samples collected in commercial d'Anjou pear orchards before harvest although, in some orchards, inoculum levels ranging from 26 to 125 CFU/g of soil were detected. These results corroborate those of Barron (2), who infrequently detected *Botrytis* spp. in the soil. *B. cinerea* is known to have a poor competitive ability in the soil (7) and a low sporulation capacity in the dark (2,10); therefore, populations of *B. cinerea* in the soil are likely to remain low. Significant population densities of *B. cinerea* were detected in litter samples collected in some commercial d'Anjou pear orchards before harvest, with levels ranging from 0 to 1,167 CFU/g. Litter provides an ideal medium for saprophytic growth of *B. cinerea* and *P. expansum* (25).

Populations of *Penicillium* spp. in soil were consistently lower than those in litter. *Penicillium* spp. are aggressive colonizers of both soil and plant litter (8,25). Their battery of enzymes and production of antimicrobial compounds (25) give them a competitive edge over other organisms (including *B. cinerea*) in both substrates. Based on the results of this study, contamination of bins with soil and litter could introduce inoculum of both *B. cinerea* and, to a greater extent, *Penicillium* spp. into the packinghouse environment, particularly into dump tank water (18,21,22).

Incidence of gray mold caused by *B. cinerea* and blue mold caused by *P. expansum* in stored d'Anjou pear fruit from several commercial orchards varied considerably over the 3 years in which fruit was stored and evaluated for decay. Currently, the pear fruit industry must maintain decay incidence at less than 2% to avoid marketing problems, and decay incidence in fruit from several of the orchards often exceeded this amount during this study.

Of all relationships between population levels of both *B. cinerea* and *Penicillium* spp. and between population levels and decay in storage, only population levels on fruit surfaces were significantly and positively correlated to decay in storage. It would appear that inoculum levels of *B. cinerea* and *Penicillium* spp. in orchard and packinghouse air and orchard soil and litter cannot be used as indicators of postharvest decay, whereas inoculum levels on fruit surfaces may prove to be useful predictors of decay. This does not imply that

inoculum in the orchard and packinghouse air and orchard soil and litter does not contribute to the epidemiology of these two pathogens in causing postharvest decay in pears. It can reasonably be assumed that inoculum produced on soil, litter, and plant material in the orchard, as detected in the orchard air, would be largely responsible for initial inoculum levels detected on fruit surfaces as they leave the orchard and enter the packinghouse environment. Our study, combined with those of Sanderson and Spotts (18) and Spotts and Cervantes (21), show that the build-up of *Penicillium* spp. inoculum in fruit stored in bins and packed late in the season is a real threat to the Pacific Northwest pear industry because considerable numbers of conidia are dispersed in dump tank water and contaminate clean fruit.

The results of this study indicate the importance of reducing the inoculum levels of these two pathogens. Current orchard management practices aimed at reducing the amount of initial inoculum involve sanitation methods such as regular mowing of grass or cover crops, removal of fallen fruit, clean bins, and a preharvest application of a contact or protectant fungicide to reduce the number of viable propagules contaminating fruit surfaces. Over-mature fruit is more susceptible to both *B. cinerea* and *P. expansum* (19); therefore, fruit should be harvested at the optimal stage of maturity to avoid infection. During harvest, fruit is handled and transported carefully to minimize wounding. Although wounds sustained by pear fruit undergo a healing process with time (24), wounded fruit are far more susceptible to decay than nonwounded fruit (21).

The controlled environment of the packinghouse provides an opportunity for the control of decay fungi through the use of sanitation and fungicides. Chlorine or sodium o-phenylphenate are used to sanitize the water in flumes (4), and captan or thiabendazole is applied as a drench or line spray in many packinghouses (1,12). Thiabendazole is effective against both *B. cinerea* and *P. expansum* (3), although resistant isolates have been detected in populations of both fungi in the Pacific Northwest (3,21). Due to residue limitations on fruit for the export market, captan is seldom used in the industry.

In conclusion, inoculum levels of these important postharvest pathogens in orchard and packinghouse air and in orchard soil and litter are not reliable as indicators of postharvest decay, whereas inoculum levels on fruit surfaces may be useful predictors of decay. Reducing inoculum levels before fruit enters the packinghouse remains the best line of defense against decay caused by *B. cinerea* and *Penicillium* spp.

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