JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY



# Residue Levels and Storage Responses of Nectarines, Apricots, and Peaches after Dip Treatments with Fludioxonil Fungicide Mixtures

SALVATORE D'AQUINO,[†] MARIO SCHIRRA,*[,†] AMEDEO PALMA,[†] MARCO TEDDE,[§] ALBERTO ANGIONI,[#] ANNA GARAU,[#] AND PAOLO CABRAS[#]

CNR Istituto di Scienze delle Produzioni Alimentari, via dei Mille, 07100 Sassari, Italy; Consorzio Provinciale per la Frutticoltura, Viale Adua 2/C, 07100 Sassari, Italy; and Dipartimento di Tossicologia, Università di Cagliari, via Ospedale 72, 09124 Cagliari, Italy

Mature apricots (*Prunus armeniaca*), nectarines [*Prunus persica* var. nectarine (Ait.)], and peaches [*P. persica* (L.) Batsch.] were subjected to a 2 min dip treatment with warm water at 48 °C or with fludioxonil (FLU) at 100 mg $L^{-1}$ and 20 °C or at 25 mg $L^{-1}$ FLU and 48 °C and then stored at 5 °C and 90−95% relative humidity (RH) for 1 week plus 1 additional week at 18 °C and approximately 80% RH. Fruit residue uptake was determined as a function of fungicide concentration, dip temperature, treatment time (only on nectarines), and fruit storage conditions. FLU residue level was closely related to fungicide concentration and treatment temperatures and was dependent on fruit species. FLU residues showed great persistence over both storage and shelf life. Fruit dipping in water at 48 °C effectively reduced decay development in cvs. 'May Grand' nectarines and 'Pelese' apricots but was ineffective in cvs. 'Red Top' and 'Sun Crest' nectarines during 7 days of storage compared with nontreated fruit. Decay rates in cvs. 'Glo Haven' peaches and 'Fracasso' apricots were very low in fruit dipped in water at both 20 and 48 °C. Fungicide treatments at 20 and 48 °C resulted in the total or almost total suppression of decay in all cultivars. During shelf life, fruit became very prone to decay, averaging 25.7−100% depending on the cultivar. Fruit dipping in hot water effectively reduced decay in 'Pelese' and 'Fracasso' apricots, 'Sun Crest' peaches, and 'May Grand' nectarines as compared to control, but was ineffective in 'Glo Haven' and 'Red Top' peaches. Fungicide treatments at 20 °C were more effective than hot water in most cultivars. The combination of FLU with water at 48 °C further improved the fungicide performance. Indeed, reduced levels (a fourth) of active ingredient were required to achieve a control of decay comparable to that for treatment at 20 °C. Residue levels in fruit after treatment with 100 mg $L^{-1}$ FLU at 20 °C or with 25 mg $L^{-1}$ FLU at 48 °C averaged approximately 0.6−2 mg $kg^{-1}$, which were notably lower than the maximum residue limit (5 mg $kg^{-1}$) allowed in the United States for stone fruit.

**KEYWORDS: Stone fruit; storage; disease control; hot water dip; heated fungicide treatments; fludioxonil; residues**

## INTRODUCTION

Decay is the main cause of postharvest losses of apricots, peaches, and nectarines. Brown rot and blue mold are the major postharvest diseases of these crops. Brown rot is caused by three closely related fungal species: *Monilinia fructicola* (G. Wint.) Honey, which is mainly present in North America, Brazil, Australia, and New Zealand; and *Monilinia laxa* (Adehold and Ruhland) Honey and *Monilinia fructigena* (Winter) Honey, which in Europe mainly affect stone fruit and pome fruit, respectively (*1*, *2*). Blue mold, caused by *Penicillium expansum* Link., is common all over the world, and although it can cause severe losses, careful handling during harvesting and packing-house operations would largely reduce the risk of infection. Other diseases such as gray mold caused by *Botrytis cinerea* and rhizopus rot caused by *Rhizopus stolonifer* also result in important postharvest fruit losses (*3*). Without fungicide treatment, losses due to such diseases can reach 50% or more, whereas the application of postharvest fungicides notably reduces losses, even to as low as 5−10% of production (*4*).

In the past, postharvest decay management of nectarines and peaches was based on dicloran (2,6-dichloro-4-nitroaniline, DCNA, botran) and/or iprodione dip treatments. Dicloran is

* Address correspondence to this author at CNR ISPA, Unità staccata di Oristano, Località Palloni, 09170 Oristano, Italy (e-mail mario.schirra@ispa.cnr.it).
[†] CNR Istituto di Scienze delle Produzioni Alimentari.
[§] Consorzio Provinciale per la Frutticoltura.
[#] Università di Cagliari.

10.1021/jf0628734 CCC: $37.00 
Published on Web 01/09/2007

effective in controlling soft-watery rot caused by *R. stolonifer* in stone fruits but is ineffective against *P. expansum* and *M. fructicola*, whereas iprodione was withdrawn from postharvest use in 1996 (*5*−*8*). More recently, new fungicides have been developed and brought to market to obviate these problems. Among them is fludioxonil (FLU), a phenylpyrrole fungicide with a mode of action different from that of other fungicides currently in use for pre- or postharvest treatments of selected fruit crops, including stone fruits in the United States.

Recent studies on stone fruits have investigated the spectrum of activity of various new reduced-risk fungicides, including fludioxonil (*9*), as well as the optimum application methods and compatibilities with the most commonly used fruit coatings, and found that these fungicides have a spectrum of activity and efficacy comparable to the banned iprodione and are highly effective in preventing decay from infections when fruits were treated before inoculation (*9*). Yet it has also been found that these fungicides have a weak curative activity due to their lack of ability to penetrate skin and enter the fruit (*10*, *11*).

Investigations on citrus fruit have shown that residue levels of FLU increased notably with increasing temperature and that when FLU was applied at 50 °C, considerably lower concentrations were required to achieve comparable performance and residues left by standard treatments with fungicide mixtures at room temperature (*12*). We thus examined (a) the interrelationships of FLU residue levels and fungicide concentration, dip temperature, treatment time, and fruit storage conditions and (b) the potential of FLU residues in controlling storage decay of apricot, nectarine, and peach fruits when the fungicide was applied in combination with hot water so as to maximize fungicide performance (*12*).

## MATERIALS AND METHODS

**Fruit.** Nectarines [*Prunus persica* var. nectarine (Ait.) ] cv. 'Venus', apricots (*Prunus armeniaca*) cvs. 'Pelese' and 'Fracasso', and peaches [*P. persica* (L.) Batsch.] cvs. 'Glo Haven' and 'Independence' were hand-harvested when commercially ripe from an experimental orchard of the "Consorzio Provinciale per la Frutticoltura di Sassari", located in northern Sardinia (Italy). Fruits were placed in plastic trays and delivered to the laboratory the same day of harvest. Then, fruits of medium size and free from rind defects were selected, returned to each box, and left overnight at 20 °C before treatments.

**Fungicide.** The fungicide used was a commercial formulation of FLU (Savior Flowable 20, Syngenta) containing 20% active ingredient (ai).

**Factors Affecting FLU Residues.** *Effect of Treatment Time.* 'Venus' nectarines were subjected to 1.0, 3.0, or 6.0 min dip treatments with 200 mg $L^{-1}$ FLU at 20 or 48 °C. Four replicates of 20 fruits per treatment were used. Apricots and peaches were not included in this study because in these fruit species fungicide residues are absorbed much more easily than in smooth-skinned or glabrous fruit, such as nectarines, in which residues are more difficult to attain, especially with a standard treatment at room temperature.

*Effect of FLU Concentration and Temperature.* 'Venus' nectarines, 'Pelese' apricots, and 'Glo Haven' and 'Red Top' peaches were subjected to treatment with 25, 50, 100, or 200 mg $L^{-1}$ FLU at 20, 30, 40, or 48 °C for 2 min. Each treatment was applied to four replicates of 20 fruit each.

*Effect of Storage Conditions.* 'Glo Haven' peaches, 'Independence' nectarines, and 'Fracasso' and 'Pelese' apricots were grouped into four groups (two fruit boxes per treatment, 40 fruits per box) used for treatment with 25 or 100 mg $L^{-1}$ FLU at 20 or 48 °C, respectively. After treatments, fruits were transferred to a ventilated room and stored at 5 °C and 90% relative humidity (RH) for 5 days (simulated transport conditions) plus 5 days of simulated shelf life at 18 °C and 80% RH. Analyses were performed at time 0 (immediately after treatment) and after shelf life.

*Chemicals.* Acetone and hexane were of GC grade (Merck, Milan, Italy). Sodium chloride was of analytical grade (Carlo Erba, Milan, Italy). The active ingredient standard, FLU (at 95%), was purchased from Dr. Ehrenstorfer (Augsburg, Germany). Stock standard solution of the ai (500 $kg^{-1}$) was prepared in acetone. Working standard solutions of the ai were prepared by diluting the stock solution with the extract from untreated fruit.

*Extraction Procedure and Residue Analysis*. Six to eight peaches and nectarines and 10 apricots per replicate were used for FLU residue analysis, after seed removal. Fruit samples were minced with a mincing knife and homogenized. For FLU extraction, 5 g of homogenized sample was weighed in a 40 mL screw-cap flask to which 10 mL of acetone/hexane (1:1) and 6 g of NaCl were added. Then, the mixtures were agitated in a rotary shaker for 20 min. Subsequently, the phases were allowed to separate, and the organic layer was injected into a gas chromatograph for the analysis without any cleanup step. Residue analysis of FLU was performed by a TQ Trace Gas Chromatographer, coupled with a NPD 80 detector, a split/splitless injector, and an AS200 autosampler (Termo Quest, Milan, Italy) as described in a previous paper (*12*). Untreated nectarines, apricots, and peaches were spiked prior to extraction by the addition of the appropriate volume of stock standard solution to reach 0.12, 0.61, 6.13, and 12.26 mg/kg of fludioxonil and processed according to the above-described procedure. The matrix effect was evaluated by comparing the analytical response of the pesticide dissolved in acetone/hexane and in control matrix extracts. Mean average recovery values from four replicates ranged between 87 and 106% with a maximum coefficient of variation (CV) of 10%. No significant differences were recorded on recovery assays among fruit species. The limit of detection according to Thier and Zeumer (*13*) was 0.03 mg/kg, and the limit of quantification (S/N = 10) was 0.08 mg/kg.

**Storage Trials.** 'Red Top' peach, 'Independence' and 'Venus' nectarines, 'Pelese' and 'Fracasso' apricots were grouped into four groups corresponding to the following 2 min dip treatments: (I) water at 20 °C (control); (II) FLU at 100 mg/L and 20 °C; (III) water at 48 °C; (IV) FLU at 25 mg/L and 48 °C. Each treatment was applied to three replicates of 120 fruits each.

Each treatment group was divided into three subgroups of 40 fruits. Fruits of the first subgroup were used for visual assessment, which included external appearance, treatment damage, and decay. Fruits of the second subgroup were used for fruit firmness and chemical analysis (percentage of soluble solids and titratable acidity of juice), whereas fruits of the remaining group were used for the determination of transpiration rate as fruit weight (mass) loss.

Once dried, fruits were stored at 5 °C and 90% RH in a ventilated room for 1 week plus 1 week of simulated shelf life at 18 °C. Quality evaluations were performed after cold storage and subsequent shelf life.

For each treatment, individually numbered fruits were inspected for external appearance (freshness), treatment damage (skin browning and pitting), decay incidence (percentage of rotten fruit caused by various fungi), and fruit weight loss. Decay incidence was assessed as total rots caused by brown rot (*Monilinia laxa* or *M. fructigena*), blue mold (*Penicillium expansum*), gray mold (*Botrytis cinerea*), rhizopus rot (*Rhizopus stolonifer*) or as miscellaneous rots of unidentified fungi. External appearance was rated in three categories: 3 = fresh (good, glossy color), 2 = fairly fresh, and 1 = not fresh (color without gloss).

Fruit weight loss was determined on three replicates of 10 fruits and was expressed as percent loss from initial weight. For fruit firmness measurements penetrative force was individually recorded on 10 fruits per replicate using a penetrometer (Effegi, fruit tester, TR di Turoni, Forlì, Italy) with an 8 mm diameter tip. For each fruit two readings were taken in the equatorial region after 1 $cm^2$ of the skin had been removed. Results were expressed in kilograms. Percentage of soluble solids content (SSC) was determined with a digital Abbe refractometer (Reichert model A1171, Vienna, Austria). Titratable acidity (TA) was determined by titrating an aliquot of juice to an endpoint of pH 8.2 with 0.1 mol $L^{-1}$ NaOH and expressing the result as percentage of malic acid.

**Statistical Analysis**. Statistical analysis was performed by Statgraphics software (Manugistics, version 5 Professional, 2000) statistical

**Table 1.** Residues of Fludioxonil in 'Venus' Nectarines Following 1, 3, or 6 min Dip Treatments with 200 mg $L^{-1}$ FLU-Based Commercially Available Fungicide Mixture at 20 or 48 °C

| | FLU residues[a] (mg $kg^{-1}$ on a whole-fruit basis) at dip temp of | |
|---|---|---|
| dip time (min) | 20 °C | 48 °C |
| 1 | 0.65 ab A | 1.23 a B |
| 3 | 0.73 b A | 1.82 b B |
| 6 | 1.29 c A | 2.94 d B |

[a] In each column grouping, means separation by Tukey's test, $P \leq 0.05$. Lower case letters relate to comparisons of the effects of dipping time, within each dip temperature. Capital letters relate to comparisons of the influence dip temperature within each treatment time.

program. Analysis of variance (ANOVA) was carried out according to a single-factor, complete randomized block design with four or three replicates for each treatment, respectively, residue analysis or visual assessment, chemical analysis, fruit weight loss, and fruit firmness.

Percentages were subjected to the ANOVA or transformed in arcsin $\sqrt{x}$ or $\sqrt{x}$ before the ANOVA, depending on the range of variation of data (*14*). Mean comparisons of the effects of treatments were calculated, when applicable, by Tukey's test, $P \leq 0.05$. Actual values are shown. To determine the pattern of FLU accumulation in fruit, plots of residue levels versus dip temperature or versus fungicide concentration were computed for each data set, and the maximum squares of correlation coefficients found were used to determine the equation of the best fit curve.

## RESULTS

**Effect of Treatment Time on Nectarines.** After application at 20 °C, the FLU residue level in 'Venus' nectarines did not change significantly when dip treatments were increased from 1 to 3 min but almost doubled after 6 min (**Table 1**). When FLU was applied at 48 °C, residues increased significantly at increasing dip times. When equal treatment time was used, FLU application at 48 °C produced residue levels that were notably higher than those left by treatment at 20 °C.

**Influence of Fungicide Concentration and Treatment Temperature on Fruit Residue Level.** After 25 mg $L^{-1}$ FLU treatment at 20 °C, the residue levels in peaches, nectarines, and apricots were 0.64, 0.13, and 0.55 mg $kg^{-1}$ (ai, on a whole-fruit basis), respectively (**Figure 1** ). When the application rate was augmented from 50 to 200 mg $L^{-1}$, the residue level increased in all samples. When equal rates of fungicide were applied, the residue levels were notably higher in fruit treated at 40 and 48 °C than in fruit treated at 20 or 30 °C. In apricots, for example, FLU residue levels at 30 °C produced a deposition approximately 0.1−0.6-fold higher than that at 20 °C, whereas residues recorded after treatments at 40 and 48 °C were ca. 0.4−1.2-fold and 0.5−2-fold higher than that of treatments at 20 °C. These temperature-dependent differences were more pronounced in peaches and, especially, in nectarines, for which FLU residues after dipping at 48 °C were 2.6−6.4-fold higher than those left at 20 °C. FLU residue accumulation trends in 'Glo Haven' peaches, 'Venus' nectarines, and 'Pelese' apricots are reported in panels **a**, **b**, and **c**, respectively, of **Figure 1** as a function of fungicide levels and dip temperatures. Its accumulation patterns were dependent on fruit species and significantly correlated to application rates and dip temperature. The maximum residue limit (MRL) set in the United States for apricots, nectarines, and peaches is 5 mg $kg^{-1}$ (*15*). In nectarines the higher levels of FLU residues were recorded after treatment with 200 mg $L^{-1}$ FLU at 48 °C, averaging 4.49 mg $kg^{-1}$, and were below the MRL set in the United States. In apricots the MRL was exceeded following treatments with 200 mg $L^{-1}$ FLU at 30−48 °C, whereas in peaches the MRL was exceeded after 200 mg $L^{-1}$ FLU application at 40 or 48 °C. The interrelationships of treatment temperature, fungicide concentration, and FLU residue uptake have already been reported for oranges (*12*).

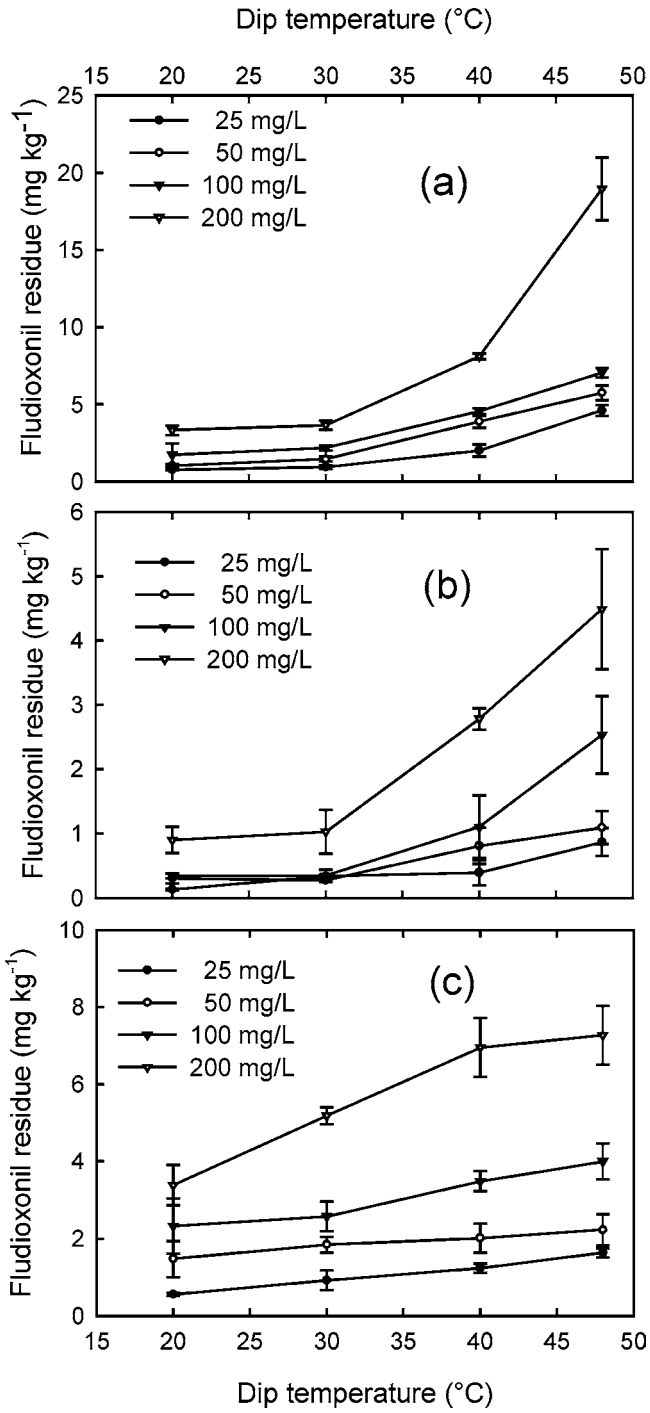


**Figure 1.** Fludioxonil (FLU) residue levels (mg $kg^{-1}$ on a whole-fruit basis) in 'Glo Haven' peaches (**a**), 'Venus' nectarines (**b**), and 'Pelese' apricots (**c**) following 2 min dip treatment with 25, 50, 100, or 200 mg $L^{-1}$ FLU-containing commercially available fungicide mixtures at 20, 30, 40, or 48 °C. Each datum point is a mean (±SE, 95% confidence) of four replicates.

**Effect of Storage Conditions.** FLU residues showed marked persistence over both storage and shelf life, remaining fairly unchanged in 'Fracasso' apricots and decreasing to a low rate in the other samples (**Table 2**).

**Table 2.** Fludioxonil Residues in 'Red Top' Peach, 'Independence' Nectarine, and 'Pelese' and 'Fracasso' Apricots Following 2 min Dip Treatment with a Commercially Available FLU-Based Fungicide Mixture (Time 0) and after Storage for 1 Week at 5 °C plus 1 Week of Simulated Shelf Life at 18 °C

| species and cultivar | FLU concn[b] (mg $L^{-1}$) | dip temp (°C) | FLU residues[a] (mg $kg^{-1}$ on a whole-fruit basis) at time 0[c] | after shelf life |
|---|---|---|---|---|
| 'Glo Haven' peach | 100 | 20 | 1.45 a B | 1.10 b A |
| | 25 | 48 | 1.93 b B | 1.40 a A |
| 'Independence' nectarine | 100 | 20 | 0.57 a B | 0.00 a A |
| | 25 | 48 | 1.52 b B | 0.72 b A |
| 'Pelese' apricot | 100 | 20 | 2.19 b A | 1.83 b A |
| | 25 | 48 | 1.26 a A | 1.03 a A |
| 'Fracasso' apricot | 100 | 20 | 1.42 b A | 1.40 b A |
| | 25 | 48 | 1.02 a A | 0.97 a A |

[a] In each row or column grouping, means separation by Tukey's test, $P \leq 0.05$. Lower case letters relate to comparisons of the effects of treatments, within each cultivar and storage time. Capital letters relate to comparisons of the influence of storage conditions, within each cultivar, and treatment. [b] The fungicide concentration refers to active ingredient. [c] Immediately after treatment.

**Fruit Storage Response to Dip Treatments.** The present study on apricots, nectarines, and peaches reveals that decay was caused mainly by *M. laxa*, *B. cinerea*, and *Rhizopus* (data not shown). After 1 week of storage at 5 °C decay incidence in untreated 'Glo Haven' and 'Fracasso' was very low, averaging 0.7 and 1.7%, respectively, and differences among treatments were not significant ($P > 0.05$) (**Table 3**). Higher decay values were recorded in the other fruit samples, ranging from 4.4% ('Sun Crest') to 11.7% ('May Grand'). Compared to untreated control fruit, FLU treatments at 20 and 48 °C were as effective as treatment with water at 48 °C in 'May Grand', 'Sun Crest', and 'Pelese', but significantly more effective in 'Red Top'. After shelf life, decay increased notably in all fruit samples, reaching ca. 28% in nectarines, 62−100% in peaches, and 57−73% in apricots. Although the effect of hot water against decay over shelf life was not significant in 'Glo Haven' and 'Red Top', it was significant in the other cultivars. During shelf life treatments with both 100 mg $L^{-1}$ FLU at 20 °C and 25 mg $L^{-1}$ FLU at 48 °C were as effective as water at 48 °C in nectarines but more effective in peaches and in 'Fracasso' apricots. Differences between fungicide treatments in decay control were not significant during either storage or shelf life.

During storage at 5 °C, all fruit samples remained relatively firm when free from diseases but quickly softened during shelf life (**Tables 4** and **5**). Peaches and nectarines showed no significant differences among treatments in fruit firmness after either storage or shelf life, although 'Pelese' and 'Fracasso' apricots had significantly lower values after storage, as a result of hot water or FLU treatment at room temperature, respectively.

Whereas mass loss rate was relatively low during storage at 5 °C, it increased notably when fruits were transferred to shelf life conditions at 20 °C (**Tables 4** and **5**). The influence of treatments was not clear. In 'May Grand' nectarines, for example, hot water treatment without or with FLU significantly increased the rate of weight loss, during either storage or shelf life. 'Red Top' had lower mass loss values in fruit treated with FLU at 20 or 48 °C, after storage. Although 'Sun Crest' had higher values in fruit treated with hot water and lower ones in those treated with FLU at 20 °C, after shelf life no treatment-dependent differences were recorded in fruit weight loss. In nectarines hot water without or with FLU increased mass loss with respect to control fruit. In 'Pelese' apricots all treatments resulted in higher values of mass loss after cold storage, whereas after shelf life no statistical differences among treatments were detected. In 'Fracasso' apricots, for example, mass loss was unaffected by treatments during either storage or shelf life. Juice pH, titratable acidity, and SSC were not significantly affected by treatments (data not shown).

## DISCUSSION

FLU dip at 48 °C for 1 min produced residue levels similar to those left by treatment at 20 °C for 6 min, suggesting that hot water at 48 °C applied in combination with FLU should make it possible to reduce dipping time from 6 to 1 min with respect to treatment at 20 °C. Reducing the time of postharvest treatments for disease control would be desirable as it could increase packinghouse output and shorten delays in fruit marketing.

Previous studies have shown the degradation trend of FLU in grapes subjected to standard field treatments (*16*). Garau et al. (*17*) elucidated the mechanism of disappearance of FLU residues from tomatoes grown in a commercial greenhouse. Investigations on lettuce and grape (*18*) revealed that when FLU was applied as a preharvest spray, dissipation rates were notably higher in the field than under storage conditions at 4 °C in the dark. Schirra et al. (*12*) reported that the dissipation rate of FLU in oranges was dependent on treatment temperature, being lower in fruit treated at 50 °C than at 20 °C. Due to FLU's slow rate of disappearance, the results of the present study did not enable evaluation of the influence of dip temperature on dissipation rate in apricots, peaches, and nectarines. As residues of FLU on the fruit surface can be removed to a large degree by washing (*11*), treatments with this fungicide will be more acceptable to the consumer than would be treatment with previously registered products.

Laboratory and packingline investigations of nectarines and peaches (*10*, *11*) have shown that FLU is highly effective against brown rot, gray mold, rhizopus decay, and other fruit rots when applied as postinfection treatment up to 18 h after inoculation, whereas established infections cannot be eradicated with FLU. The efficacy of FLU as a preinfection treatment was found to be inconsistent (*10*, *11*). On the other hand, studies on cv. 'Empire' apples (*19*) have shown that FLU treatments have both curative and protective action against blue mold caused by *P. expansum*. The total suppression of TBZ-resistant and -sensitive strains of *P. expansum* in apples stored for 105 days under controlled atmosphere at 2 °C or for 42 days in standard storage conditions at 4 °C was achieved with 300 mg $L^{-1}$ FLU, although higher rates (450 mg $L^{-1}$) were required to achieve complete control of blue mold during the subsequent 6 days of simulated shelf life at 20 °C (*20*).

The present study on apricots, nectarines, and peaches reveals that postharvest treatments with FLU effectively controlled decay caused mainly by *M. laxa*, *B. cinerea*, and *Rhizopus* and that, when FLU was applied in combination with water at 48 °C, a fourth of the active ingredient was needed to achieve a comparable control of decay in comparison to treatment at 20 °C. Similar results have been reported on oranges treated with FLU (*10*) or with different novel, broad spectrum fungicides such as trifloxystrobin (*21*) and pyrimethanil (*22*). After fungicide application, the FLU residue levels in apricots, nectarines, and peaches averaged approximately 0.6−2 mg $kg^{-1}$, which were notably lower than the MRL set in the United States for these fruits. Early studies by Wells and Harvey (*23*) reported positive synergistic effects of combined chemical and hot water

**Table 3.** Influence of Postharvest Dip Treatments on Decay Percentage in Nectarine Cv. 'May Grand', Peach Cvs. 'Glo Haven', 'Red Top', and 'Sun Crest', and Apricot Cvs. 'Pelese' and 'Fracasso' after 1 Week of Storage at 5 °C and a Subsequent 1 Week of Simulated Marketing Conditions at 18 °C[a]

| | nectarine | peach | | | apricot | |
|---|---|---|---|---|---|---|
| treatment | 'May Grand' | 'Glo Haven' | 'Red Top' | 'Sun Crest' | 'Pelese' | 'Fracasso' |
| | | | 1 Week at 5 °C | | | |
| water, 20 °C | 11.7 b | 0.7 a | 9.2 b | 4.4 b | 7.5 b | 1.7 a |
| water, 48 °C | 0.8 ba | 0.7 a | 5.8 b | 3.3 ab | 0.0 a | 0.0 a |
| FLU, 100 mg $L^{-1}$, 20 °C | 0.0 a | 0.0 a | 0.0 a | 2.2 ab | 0.0 a | 0.0 a |
| FLU, 25 mg $L^{-1}$, 48 °C | 0.0 a | 0.0 a | 0.0 a | 0.0 a | 0.0 a | 0.0 a |
| | | | 1 Week at 5 °C plus 1 Week at 18 °C | | | |
| water, 20 °C | 27.5 b | 93.0 b | 100 b | 62.2 c | 72.5 c | 56.7 c |
| water, 48 °C | 5.8 a | 91.0 b | 100 b | 36.7 b | 22.5 b | 22.5 b |
| FLU, 100 mg $L^{-1}$, 20 °C | 0.0 a | 10.7 a | 15.0 a | 7.8 a | 13.3 ab | 2.5 a |
| FLU, 25 mg $L^{-1}$, 48 °C | 0.0 a | 7.3 a | 16.7 a | 3.3 a | 9.2 a | 0.8 a |

[a] Values are the mean of three replicates (40 fruits per replicate). The fungicide concentrations refer to active ingredient. Treatments are 2 min dip followed by air-drying of fruit. Different letters indicate statistical differences as per Tukey's test, $P \leq 0.05$.

**Table 4.** Influence of Postharvest Dip Treatments on Fruit Firmness and Weight Loss in 'Glo Haven', 'Red Top', and 'Sun Crest' Peaches after 1 Week of Storage at 5 °C and a Subsequent 1 Week of Simulated Marketing Conditions at 18 °C[a]

| | 'Glo Haven' | | 'Red Top' | | 'Sun Crest' | |
|---|---|---|---|---|---|---|
| treatment | fruit firmness (kg) | weight loss (%) | fruit firmness (kg) | weight loss (%) | fruit firmness (kg) | weight loss (%) |
| | | | At Harvest | | | |
| | 5.43 | | 3.65 | | 4.0 | |
| | | | 1 Week at 5 °C | | | |
| water, 20 °C | 4.78 a | 2.32 a | 3.37 a | 4.03 b | 4.22 a | 3.44 b |
| water, 48 °C | 4.59 a | 2.09 a | 3.28 a | 4.28 b | 4.34 a | 4.26 c |
| FLU, 100 mg $L^{-1}$, 20 °C | 4.83 a | 2.22 a | 3.10 a | 3.18 a | 4.14 a | 2.80 a |
| FLU, 25 mg $L^{-1}$, 48 °C | 4.41 a | 2.31 a | 3.25 a | 3.47 a | 3.78 a | 3.39 b |
| | | | 1 Week at 5 °C plus 1 Week at 18 °C | | | |
| water, 20 °C | 0.611 a | 8.01 ab | 0.36 a | 8.04 b | 0.531 a | 4.90 a |
| water, 48 °C | 0.529 a | 7.64 a | 0.32 a | 8.53 b | 0.538 a | 5.50 a |
| FLU, 100 mg $L^{-1}$, 20 °C | 0.549 a | 9.01 c | 0.30 a | 6.96 a | 0.481 a | 5.16 a |
| FLU, 25 mg $L^{-1}$, 48 °C | 0.559 a | 8.56 bc | 0.34 a | 7.29 a | 0.448 a | 5.11 a |

[a] Values are the mean of three replicates (10 fruits per replicate). The fungicide concentrations refer to active ingredient. Treatments are 2 min dip followed by air-drying of fruit. Different letters indicate statistical differences as per Tukey's test, $P \leq 0.05$.

**Table 5.** Influence of Postharvest Dip Treatments on Fruit Firmness and Weight Loss in 'May Grand' Nectarines and 'Pelese' and 'Fracasso Apricots after 1 Week of Storage at 5 °C and a Subsequent 1 Week of Simulated Shelf Life at 18 °C[a]

| | nectarine | | apricot | | | |
|---|---|---|---|---|---|---|
| | 'May Grand' | | 'Pelese' | | 'Fracasso' | |
| treatment | fruit firmness (kg) | weight loss (%) | fruit firmness (kg) | weight loss (%) | fruit firmness (kg) | weight loss (%) |
| | | | At Harvest | | | |
| | 6.62 | | 2.69 | | 2.65 | |
| | | | 1 Week at 5 °C | | | |
| water, 20 °C | 5.85 a | 2.11 a | 2.25 b | 4.24 a | 2.37 b | 5.17 a |
| water, 48 °C | 5.92 a | 3.04 c | 1.66 a | 4.74 b | 2.21 ab | 4.95 a |
| FLU, 100 mg $L^{-1}$, 20 °C | 6.13 a | 2.38 ab | 1.97 ab | 4.70 b | 1.98 a | 5.05 a |
| FLU, 25 mg $L^{-1}$, 48 °C | 6.20 a | 2.77 bc | 1.98 ab | 5.37 c | 2.44 b | 5.10 a |
| | | | 1 Week at 5 °C plus 1 Week at 18 °C | | | |
| water, 20 °C | 0.82 a | 7.49 a | <0.2 a | 14.52 a | <0.2 a | 14.90 a |
| water, 48 °C | 0.84 a | 8.69 b | <0.2 a | 14.05 a | <0.2 a | 14.62 a |
| FLU, 100 mg $L^{-1}$, 20 °C | 0.82 a | 8.33 ab | <0.2 a | 14.14 a | <0.2 a | 14.58 a |
| FLU, 25 mg $L^{-1}$, 48 °C | 0.80 a | 9.14 b | <0.2 a | 13.72 a | <0.2 a | 14.97 a |

[a] Values are the mean of three replicates (40 fruits per replicate). The fungicide concentrations refer to active ingredient. Treatments are 2 min dip followed by air-drying of fruit. Different letters indicate statistical differences as per Tukey's test, $P \leq 0.05$.

treatments on peaches, plums, and nectarines. They demonstrated that a 1.5 min dip with 2,6-dichloro-4-nitroaniline (DCNA) at 51.5 °C was much more effective in controlling decay, mainly caused by *M. fructicola*, than treatments with hot water or DCNA (dicloran, botran) performed at room temperature (24 °C). After treatment with 225 mg $L^{-1}$ botran at 51.5 °C, the residue levels on fruit were similar to those of 900 mg $L^{-1}$ botran dips at room temperature. Decay develop-

ment in peaches, plums, and nectarines and in fruit inoculated with *Monilinia* and *Rhizopus* decreased linearly as treatment time increased from 0.5 to 3 min when 225 or 450 mg $L^{-1}$ DCNA was added to hot water. Shorter exposure time, lower temperature, and reduced fungicide rates were required to achieve similar decay control of separate treatments (*23*). Hot water at 52 °C applied in combination with TBZ, benomyl, captan, or botran enabled dip time to be reduced from 15 to 0.5 min without affecting decay control. Heated botran or benomyl was similarly or more effective than unheated fungicides in controlling *M. fructicola* in peaches (*24*). When thiabendazol, benomyl, captan, or dichloran was applied at a fourth of the recommended rates for 1.5−2 min at 51.5 or 54.5 °C, they were equally or more effective in controlling brown rot in sweet cherries, peaches, and nectarines than standard fungicide treatments at room temperature (*25*). A 2.5 min dip treatment in 46 °C water containing 100 mg $L^{-1}$ benomyl effectively controlled decay of peaches and nectarines during storage at 0 °C and during ripening at 18.°C, without injuring the fruit, whereas treatment in 46 °C water only partially controlled decay. Water treatment at 52 °C effectively controlled decay of peaches during storage but was ineffective during ripening. This treatment did not adversely affect nectarines but caused severe injuries to peaches (*26*). The nectarines, apricots, and peaches used in our study did not show any visible external injury (skin browning or pitting) due to hot water or FLU either immediately after treatment or after each a storage period (data not shown). Whereas peaches and nectarines were unaffected by treatments after either storage or shelf life, 'Pelese' and 'Fracasso' apricots had significantly lower values as a result of hot water or FLU treatment at room temperature, respectively. Previous investigations (*27*) have shown that flesh firmness of nectarines treated for 25 min with 46 °C hot water containing 200 mM NaCl was similar to that of control fruit. On the other hand, in cv. 'Caldesi 2000' nectarines and cv. 'Royal Glory' peaches 46 °C hot water reduced firmness loss when fruits were sealed in low thick polyethylene bags and stored at 0 °C for 1 or 2 weeks (*28*). This delay in flesh softening was thought to depend on a combination of hot water, modified atmosphere, and packaging, especially in the white-flesh nectarines, which kept the cellular membranes functioning better, and in part on inactivation of cell wall hydrolytic enzymes, mainly polygalacturonase (*29*).

In conclusion, postharvest treatments with FLU represent an effective tool in managing all of the major postharvest decay fungi on peaches, apricots, and nectarines. Low rates of FLU (100 mg $L^{-1}$) at 20 °C effectively controlled the causal agents of decay (natural infections). The combination of FLU with water at 48 °C further improved the fungicide performance, as reduced levels (25 mg $L^{-1}$) of fungicide were required to achieve a comparable control of decay in comparison to treatment at 20 °C. Fludioxonil has been registered on stone fruits for brown rot, gray mold, rhizopus rot, and mucor, gibertella decay. On a commercial scale, it has been recommended to treat fruit at registered rates of FLU as lower rates may be ineffective in managing postharvest decay and result in the development of resistant populations of postharvest pathogens (*10*). However, taking into account the close inter-relationships found in the present study of FLU residue uptake, fungicide level, and treatment temperature, when treatment is performed in combination with water at 48 °C, FLU rates should be reduced accordingly to avoid higher residue levels than the MRL set for stone fruits.

## ACKNOWLEDGMENT

We gratefully acknowledge Syngenta Crop Protection (Italy) for kindly supplying the commercial formulation of fludioxonil.

## LITERATURE CITED

(1) Barkai-Golan, R. *Postharvest Diseases of Fruits and Vegetables. Development and Control*; Elsevier Science: Amsterdam, The Netherlands, 2001; 418 pp.
(2) Bugiani, R.; Mari, M.; Ceredi, G.; Antoniacci, L.; Montuschi, C. Moniliosi del pesco in campo e post-raccolta. *Inf. Agrar.* **2006**, *25*, 61−68.
(3) Eckert, J. W.; Ogawa, J. M. The chemical control of postharvest diseases: deciduous fruits, berries, vegetables and root/tuber crops. *Annu. Rev. Phytopathol.* **1988**, *26*, 433−469.
(4) Margosan, D. A.; Smilanick, J. L.; Simmons, G. F.; Henson, D. J. Combination of hot water and ethanol to control postharvest decay of peaches and nectarines. *Plant Dis.* **1997**, *81*, 1405−1409.
(5) Daines, R. H. Effects of fungicide dip treatments and dip temperatures on postharvest decay of peaches. *Plant Dis. Rep.* **1970**, *54*, 764−767.
(6) Lurie, S.; Droby, S.; Chalupowicz, L.; Chalutz, E. Efficacy of *Candida oleophila* strain 182 in preventing *Penicillium expansum* infection of nectarine fruits. *Phytoparasitica* **1995**, *23*, 231−234.
(7) Spotts, R. A.; Cervantes, T. J.; Facteau, T. J.; Chang-Goyal, T. Control of brown rot and blue mold of sweet cherry with preharvest iprodione, postharvest *Cryptococcus infirmo-minatus*, and modified atmosphere packaging. *Plant Dis.* **1998**, *82*, 1158−1161.
(8) Spotts, R. A.; Cervantes, T. J.; Facteau, T. J. Integrated control of brown rot of sweet cherry with a preharvest fungicide, a postharvest yeast, modified atmosphere packaging, and cold storage temperature. *Postharvest Biol. Technol.* **2002**, *24*, 251−257.
(9) Adaskaveg, J. E.; Förster, H. New detection and management practices for brown rot of peach in California. *Acta Hortic.* **2002**, *592*, 637−643.
(10) Adaskaveg J. E.; Förster, H.; Crisosto C. H. Stone fruit decay challenges in the spring season of 2003. The top ten tips for decay control. *Cent. Valley Postharvest Newsl.* **2003**, *No. 2*, 2−4.
(11) Adaskaveg, J. E.; Förster, H.; Gubler, W. D.; Teviotdale, B. L.; Thompson, D. F. Reduced-risk fungicides help manage brown rot and other fungal diseases of stone fruit. *California Agric.* **2005**, *59* (2), 109−114.
(12) Schirra, M.; D'Aquino, S.; Palma, A.; Marceddu, S.; Angioni, A.; Cabras, P.; Scherm, B.; Migheli, Q. Residue level, persistence and storage performance of citrus fruit treated with fludioxonil. *J. Agric. Food Chem.* **2005**, *53*, 6718−6724.
(13) Thier, H. P., Zeumer, H., Eds. *Manual of Pesticide Residue Analysis*; VCH: Weinheim, Germany, 1987; Vol. 1, pp 37−44.
(14) Gomez, K. A.; Gomez, A. A. *Statistical Procedures for Agricultural Research*; Wiley: New York, 1984; 680 pp.
(15) USDA Foreign Agricultural Services MRL Data Base, 2006, www.mmrldatabase.com.
(16) Cabras, P.; Angioni, A.; Garau, V. L.; Melis, M.; Pirisi, F.; Minelli, E. V.; Cabitza, F.; Cubeddu, M. Fate of some new fungicides (cyprodinil, fludioxonil, pyrimethanil, and tebuconazole) from vine to wine. *J. Agric. Food Chem.* **1997**, *48*, 2708−2710.
(17) Garau, V. L.; Angioni, A.; Aguilera Del Real, A.; Russo, M. T.; Cabras P. Disappearance of azoxystrobin, cyprodinil, and fludioxonil on tomato in a greenhouse. *J. Agric. Food Chem.* **2002**, *50*, 1929−1932.
(18) Marin, A.; Oliva, J.; Garcia, C.; Navarro, S.; Barba, A. Dissipation rates of cyprodinill and fludioxonil in lettuce and table grape in the field and under cold storage conditions. *J. Agric. Food Chem.* **2003**, *51*, 4708−4711.

(19) Errampalli, D. Effect of fludioxonil on germination and growth of *Penicillium expansum* and decay in apple cvs Empire and Gala. *Crop Prot.* **2004**, *23*, 811−817.
(20) Errampalli, D.; Northover, J.; Skog, L.; Brubacher, N. R.; Collucci, C. A. Control of blue mold (*Penicillium expansum*) by fludioxonil in apples (cv Empire) under controlled atmosphere and cold storage conditions. *Pest Manag. Sci.* **2005**, *61*, 591−596.
(21) Schirra, M.; D'Aquino, S.; Palma, A.; Angioni, A.; Cabras, P.; Migheli, Q. Residues of the quinone outside inhibitor fungicide trifloxystrobin after postharvest dip treatments to control *Penicillium* spp. on citrus fruit. *J. Food Prot.* **2006**, *69*, 1646−1652.
(22) D'Aquino, S.; Schirra, M.; Palma, A.; Angioni, A.; Cabras, P.; Migheli, Q. Residue levels and effectiveness of pyrimethanil vs imazalil when using heated postharvest dip treatments for control of *Penicillium* decay on citrus fruit. *J. Agric. Food Chem.* **2006**, *54*, 4721−4726.
(23) Wells, J. M.; Harvey, J. M. Combination heat and 2,6-dichloro-4-nitroaniline treatments for control of *Rhizopus* and brown rot of peaches, plums, and nectarines. *Phytopathology* **1970**, *60*, 116−120.
(24) Smith, W. L., Jr. Control of brown rot and *Rhizopus* of inoculated peaches with hot water and hot chemical suspensions. *Plant Dis. Rep.* **1971**, *55*, 228−230.
(25) Jones, A. L.; Burton, C. Heat and fungicide treatments to control postharvest brown rot of stone fruits. *Plant Dis. Rep.* **1973**, *57*, 62−66.
(26) Smith, W. L.; Anderson, R. E. Decay control of peaches and nectarines during and after controlled atmosphere and air storage. *J. Am. Soc. Hortic. Sci.* **1975**, *100*, 84−86.
(27) Obenland, D. M.; Aung, L. H. Sodium chloride reduces damage to nectarines caused by hot water treatments. *Postharvest Biol. Technol.* **1997**, *12*, 15−19.
(28) Malakou, A.; Nanos, G. D. A combination of hot water treatment and modified atmosphere packaging maintains quality of advanced maturity 'Caldesi 2000' nectarines and 'Royal Glory' peaches. *Postharvest Biol. Technol.* **2005**, *38*, 106−114.
(29) Lurie, S. Postharvest heat treatments. *Postharvest Biol. Technol.* **1998**, *14*, 257−281.

**Received for review October 6, 2006. Revised manuscript received November 9, 2006. Accepted November 9, 2006. Study supported by Research Project: Studi sul Germoplasma Autoctono di Piante da Frutto in Sardegna − legge 23 dicembre 1999 no. 499 art. 3.**

JF0628734