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EVALUATION OF CURRENT INDUSTRY PRACTICES FOR MAINTAINING TOMATO DUMP TANK WATER QUALITY DURING PACKINGHOUSE OPERATIONS

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ABSTRACT

Maintenance of adequate sanitizer levels in tomato dump tanks is critical to preventing pathogen survival and transfer, and internalization in the fruit. However, the rapid accumulation of organic matter in dump tanks can cause a significant decline in sanitizer concentration, thus leaving wash solutions vulnerable to becoming a reservoir for pathogens. This study investigated the dynamic changes in wash water quality and sanitizer concentration during routine operations of three medium to large tomato packinghouses in Florida in 2010 and 2011. Overall, water quality declined continuously during packinghouse operations, as exhibited by significant increases in chemical oxygen demand and turbidity. Free chlorine concentration, oxidation reduction potential and pH fluctuated largely as a consequence of periodic addition of sodium hypochlorite and citric acid, and the rapid loss of free chlorine caused by organic matter. Although the packinghouses differed significantly in system configuration, operation and chlorine dosing rates, at least 25 mg/L of free chlorine concentrations were maintained in all of the dump tanks surveyed.

PRACTICAL APPLICATIONS

Wash water quality and sanitizer strength are important factors influencing food safety of tomatoes washed in packinghouses. Soil, debris and juices from damaged fruits entering dump tanks along with tomatoes can cause water quality and sanitizer strength to decline dramatically, leaving wash solutions vulnerable to the growth of harmful bacteria. Maintenance of adequate sanitizer levels in tomato dump tanks is critical to reducing pathogen survival, transmission and incidence of internalization in the fruit. The researchers surveyed the water quality and sanitizer concentrations during routine operations of three major tomato packinghouses in Florida in 2010 and 2011. The results are useful for the regulatory agency and tomato industry in developing packinghouse handling guidelines to maintain the quality and food safety of tomatoes.

INTRODUCTION

Several foodborne illness outbreaks that significantly impacted the U.S. economy have been associated with consumption of contaminated tomatoes (Barak and Liang 2008; Fatica and Schneider 2011). Contaminated water used in postharvest processing has been implicated in some of these tomato-associated outbreaks. Such contamination can occur when operations fail to recondition wash water effectively and maintain sufficient levels of sanitizers. Thus, wash water sanitation is an important control point for food safety in tomato packing facilities (Simons and Sanguansri1997; Hedberg *et al.* 1999; Sivapalasingam *et al.* 2004; Gil *et al.* 2009; Hanning *et al.* 2009).

Chlorine is a sanitizer commonly used in dump tank and flume water in tomato packinghouses (Boyette *et al.* 1993; Tomas-Callejas *et al.* 2012) because of its established ability to kill pathogens in suspensions and minimal impact on product quality (Adams *et al.* 1989; Brackett 1992; Zhuang *et al.* 1995; Sapers 1998; Cherry 1999; Izumi 1999; Beuchat *et al.* 2004; Ortega and Sanchez 2010). The antimicrobial properties of chlorine compounds primarily result from the formation of hypochlorous acid by hydrolysis. Hypochlorous acid is highly reactive with organic nitrogen in the presence of oxygen (Garrett 1992; Zagory 2000) and is also significantly affected by pH, temperature, light and metals (Anon 2013).

Dump tanks or flume systems are widely used to wash tomatoes commercially, especially in Florida, which contributes to at least 40% of the U.S. tomato production. Although limited studies show that a non-recirculated, overhead spray brush roller system could minimize the reuse of wash water and its associated potential for pathogen cross-contamination, the pros and cons of this new system need to be further evaluated before it can be widely adopted by the industry (Beuchat *et al.* 1998; Chang and Schneider 2012). Currently, mature green tomatoes are often handpicked in 30-lb (14 kg) half bushel baskets, transferred to bins and transported to the packinghouses for further sorting, washing and packing for sale. At the packinghouse, tomatoes are usually emptied from bins into dump tanks where water is used to cushion the fall to prevent mechanical damage. Due to cost of operation and environmental constraints on water usage, the large volume of water used in dump tanks and/or flumes in commercial packinghouses is reused throughout the daily operation (Lopez-Velasco *et al.* 2012; Tomas-Callejas *et al.* 2012; Toor *et al.* 2012). Waxes, soil, dust, pesticide residues, leaf debris and organic exudates from damaged fruits enter dump tank or flume water, and cause rapid deterioration of wash water quality, depletion of hypochlorous acid and formation of toxic chlorinated by-products (Wei *et al.* 1995; Pirovani *et al.* 2001; Shang and Blatchley 2001; Donnermair and Blatchley 2003). Insufficient free chlorine concentration leaves the wash water vulnerable to contamination by spoilage microorganisms, plant pathogens and human pathogens, and facilitates the potential spread of microbial contaminates among subsequently washed tomatoes (Segall 1968; Segall and Dow 1976; Bartz *et al.* 2001; Harris *et al.* 2003; Rogers *et al.* 2004; Yuk *et al.* 2005; Tomas-Callejas *et al.* 2012).

The need for maintaining sufficient chlorine concentration in dump tanks to kill plant pathogens and prevent their internalization has been recognized for several decades (Brackett 1992; Sapers 1998; Beuchat *et al.* 2004; Bartz *et al.* 2009). A concentration of 100–300 mg/L chlorine was used to ensure that the residual post-wash free chlorine concentration would be sufficient to achieve a rapid bactericidal effect (Hicks and Segall 1974; Bartz *et al.* 2001). Earlier tomato best management practices (T-BMP) adopted this practice and required a minimum of 150 mg/L chlorine in tomato dump tanks for preventing human pathogen survival and internalization in tomatoes (Anon, 2007). Lacking scientific information to validate the need for this high chlorine concentration and considering the ambiguity concerning the concentration of free chlorine needed to control pathogens, the requirement for 150 mg/L of chlorine was replaced with that for an oxidation reduction potential (ORP) reading of 650 mV in the commodity-specific food safety guidelines for the fresh tomato supply (Anon 2008). Several studies have also questioned the accuracy of ORP measurement and pointed out the nonlinearity of its relationship with sanitizer concentration (Schneider *et al.* 2011; Suslow 2004, 2012). Recent research (Luo *et al.* 2011) has shown that although as little as 0.5 mg/L free chlorine will limit *Escherichia coli* O157:H7 survival in the wash solution; 10 mg/L of free chlorine is necessary to prevent pathogen cross-contamination during fresh-cut leafy green wash. However, the minimum chlorine concentration required to prevent *Salmonella* survival and internalization is unknown. In addition, the scientific information regarding how, where and when to add or measure chlorine is lacking. Consequently, each packinghouse follows a different protocol for addition and monitoring of free chlorine.

In addition to maintaining sanitizer concentrations, T-BMP also requires that dump tank operators maintain at least 5.56C differential between dump tank water and the incoming tomato pulp temperature, and that tomatoes remain in the dump tank no longer than 2 min and be loaded no more than two layers of tomatoes deep. All these critical food safety standards are instituted to prevent possible pathogen internalization during dump tank washing. However, during development of these control point "metrics" and limits, a number of important data gaps were identified (CPS 2009). It is recognized that dump tank water quality parameters such as turbidity, pH, sanitizer level and temperature play critical roles in controlling sanitizer efficacy and preventing pathogen infiltration/contamination (Garg *et al.* 1990). However, clear documentation of the current commercial operation is lacking.

Therefore, the main objective of this study was to document the dynamic changes of water quality and sanitizer concentration during commercial tomato packinghouse operations. Information can be used to determine areas in which improvement can be made to key standard sanitation operational procedures, and to develop functional limits operators can use to maintain dump tank sanitizer concentrations and other control parameters at effective levels to ensure food safety.

MATERIALS AND METHODS

Tomato Packing Facilities

Three cooperating tomato packinghouses in Florida were visited during the 2010 and 2011 tomato production seasons. Packinghouse I employed a combined system of chlorine dioxide generation and sodium hypochlorite injection. Packinghouses II and III employed a sodium hypochlorite injection system. In general, the wash systems of the three packinghouses consisted of either a single- or double-wash tank and a flume system and their associated recirculation system tanks with screening units for large debris removal.

Water Quality Measurements

Baseline dump tank water quality was determined during commercial packinghouse operations. The volume of water in the dump tank and the weight of the dumped tomatoes were recorded. Water samples (500 mL) were taken from the dump tank every 30 min in packinghouse I during the entire 4-h operation, or every 15 min in packinghouses II and III during the entire 8.0- and 3.5-h operations, respectively. Most water quality parameters were tested on site, including total and free chlorine, pH, ORP, turbidity and total dissolved solids (TDSs). Water samples for chemical oxygen demand (COD) testing were collected at 2-h intervals and shipped under refrigeration to the United States Department of Agriculture–Agricultural Research Service laboratory in Beltsville, MD, and tested within 2 days. Chlorine was measured using the N,N-diethyl-p-phenylenediamine (DPD) method using a chlorine photometer (HF Scientific Inc., Fort Myers, FL). Temperature and pH were measured using a handheld pH meter (Oakton Instruments, Vernon Hills, IL), and ORP determined using an ORP meter (Oakton Instruments). Turbidity was tested using an AQUAfast AQ4500 turbidimeter (Thermo Orion Research Inc., Beverly City, MA), and TDS measured using a conductivity meter (Thermo Scientific Orion, Beverly City, MA). COD was measured using a reactor digestion method (COD2 mercury-free COD reagent; Hach Company, Loveland, CO). All water quality measurements were conducted in triplicate.

Statistical Analysis

A completely randomized design was employed in the packinghouse survey with the operation time as the main factor. Statistical analyses were performed using the MIX procedure function of the Statistical Analysis System (version 9.2; SAS Institute, Cary, NC). When effect(s) was statistically significant, mean comparisons were performed with Sidak-adjusted P value so that the experiment-wise error (α) was smaller than 0.05. A correlation matrix for all physicochemical parameters was constructed using the CORR procedure of SAS, which provided a value for the Pearson correlation (R) and the associated P value.

RESULTS AND DISCUSSION

Water Physicochemical Conditions of Packinghouse I

Packinghouse I is a medium-sized tomato-packing facility belonging to a leading family-owned growing and packing company based in North Florida (Palmetto, FL). This facility has a two-flume tomato washer, each with a capacity of 20,000 gal (75,708 L) of water. Water lost from the primary tank is replenished with water from the secondary tank at 1.0–1.5-h intervals, whereas the secondary tank is topped off using precooled fresh tap water. The initial settings for the primary and secondary tanks are shown in Table 1. The pH was monitored in real time and continuously adjusted using citric acid. Free chlorine was manually tested by the operators on an hourly basis, and replenished as needed based on the measurement. This packinghouse facility operated for 4 h on the day of the survey.

Tomatoes were harvested under dry atmospheric conditions to minimize the potential for soil to cling to the fruits and therefore reduce damage from soil abrasion. Field managers monitored tomato maturity by slicing selected fruit with a sharp knife: if seeds were not cut and locules were full of jelly, the fruit was determined to have reached adequate maturity for harvest. Workers are instructed to remove stems from tomatoes at harvest to prevent damage from stems piercing tomato flesh. Workers pick an average of 250 baskets of approximately 30 lb (14 kg) of tomatoes per day. Full baskets were emptied into pallet bins of approximately 1,000 lb (454 kg) of tomatoes each. Tomatoes were transported to packinghouses and dumped into dump

TABLE 1. INITIAL OPERATIONAL PARAMETER SETTINGS FOR THREE PACKINGHOUSES

Packinghouse	Parameters	Primary tank	Secondary tank
I	pH	7.0–7.5	6.8–7.2
	Free chlorine (mg/L)	350	250
	ORP (mV)	930	960
II	pH	6.8–7.2	6.8–7.2
	Free chlorine (mg/L)	150	80–90
	ORP (mV)	899	520
III	pH	6.5–7.0	–
	Free chlorine (mg/L)	175	–
	ORP (mV)	870	–

ORP, oxidation reduction potential.

tanks/wash tanks usually within 3–4 h of harvest. Soil, dried leaves, insects, tomato exudates and other debris entering the dump tank were observed.

Tomatoes were dumped at a rate of 120 bins/h or approximately 120,000 lb/h. Residence time in the primary dump tank was about 30 s, whereas residence in the secondary tank was about 50 s. The water temperature of both dump tanks were 41.67C, and the tomatoes had an average pulp temperate of 35C. Tomatoes were sequentially washed in primary and secondary tanks, followed by a final spray with 5 mg/L chlorine dioxide solution before packing. In the primary tank, pH remained at 7.0–7.5, free chlorine started at 350 mg/L and declined steadily to 100 mg/L, turbidity increased from 3 to 38 NTU, COD increased from 130 to 390 mg/L and ORP remained steady at 950 mV (Figs. 1 and 2). Water quality changed very little in the second tank with COD only increasing from 135 to 150 mg/L over the course of the 4-h operation.

Water Physicochemical Condition of Packinghouse II

Packinghouse II is a medium-sized packing facility belonging to a private company categorized under whole fruits and vegetables also in North Florida (Palmetto, FL). This packinghouse has a two-flume tomato washer, with a capacity of 8,000 gal of water in the primary tank and 800 gal in the secondary tank. Wash water is recirculated, separately, in both tanks. Water lost from the primary tank is replenished with water from the secondary tank to maintain a constant level in the primary tank, whereas the secondary tank is topped off using precooled fresh water. The initial settings in the primary and secondary tanks are shown in Table 1. The pH was monitored in real time and constantly adjusted using citric acid, and free chlorine was determined manually using a DPD method and maintained using concentrated sodium hypochlorite. This packinghouse facility operated for 8 h on the day of the survey. Round tomatoes were washed first, followed by Roma tomatoes.

Tomatoes were harvested under dry atmospheric conditions using practices similar to those employed in packinghouse I. Round tomatoes are transported to packinghouses and dumped into dump tanks/wash tanks usually within 0.5–5.0 h (or up to 24 h according to the packinghouse manager) of harvest. Roma tomatoes are transported from fields to rooms where they are exposed to ethylene gas for 24–72 h until reaching the pink or slightly red stage (external appearance >25%), and then dumped into dump tanks/wash tanks.

Tomatoes were dumped into the primary tank at a rate of 180 bins/h (approximately 180,000 lb/h) for round tomatoes and 60 bins/h (approximately 60,000 lb/h) for Roma tomatoes. Subsequently, tomatoes were channeled through water in the secondary tank. Residence time in the primary tank was about 90 s, whereas residence in the secondary tank was about 30 s. The internal temperature of tomatoes was monitored frequently by the packinghouse operators, and the water temperature of the primary tank was continually adjusted to maintain at least 5.56C positive temperature differential between tank water and tomato pulp. During the 8 h of operation, packinghouse II had great fluctuation in ORP, free chlorine and pH, especially during the period from 2 to 4 h (Figs. 1 and 2). The pH was maintained from 5.5 to 6.5 except during a period of approximately 2.5 h when the pH dropped down to 3.5. Free chlorine started at 150 and varied from 110 to 275 mg/L; concentrated chlorine was added about once every hour except during the period when no tomatoes were washed; turbidity increased from 1.39 to 74.90 NTU; COD increased from 152 to 732 mg/L and ORP varied from 900 to over 1,100 mV. Water quality also changed in the second tank with COD increasing from 147 to 730 mg/L over the course of the 8-h monitoring period.

Water Physicochemical Condition of Packinghouse III

Unlike the other two packinghouses, packinghouse III is a large-sized packing facility belonging to a private company categorized under vegetable packing services in North Florida (Ruskin, FL) and has a single-flume tomato washer, with a capacity of 9,600 gal of water in the dump tank. Water lost in the dump tank is replenished with precooled fresh water. The initial settings in the single tank are shown in Table 1. The pH was monitored in real time and automatically adjusted with citric acid. Free chlorine was maintained with continual multipoint injection of sodium hypochlorite based on ORP values. Free chlorine was also determined manually using a Hydrion chlorine dispenser (CM-240; Micro Essential Laboratory, Brooklyn, NY). This packinghouse facility operated for 4 h on the day of the survey.

Tomatoes were harvested under dry atmospheric conditions using the same practices as those employed in packinghouses I and II. Tomatoes were transported to packinghouse and dumped into dump tanks/wash tanks usually within 2–5 h (sometimes 24 h according to the operator) of harvest.

Tomatoes were dumped at a rate of 180 bins/h (approximately 180,000 lb/h) in the dump tank. The fruit residence time in the tank was 30–45 s. Water temperature was 40C, and the internal fruit temperature was 30C. After moving through the single tank, tomatoes were air dried and waxed before packed for transport. During the 4 h that the system was monitored, the dump tank water quality parameters in packinghouse III remained very stable (Figs. 1 and 2).

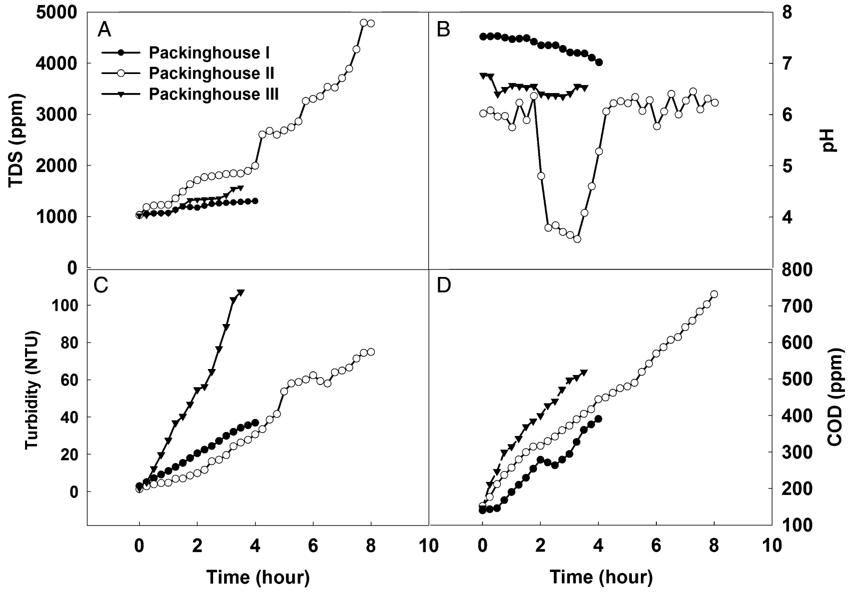

FIG. 1. TOMATO DUMP TANK WATER QUALITY PARAMETERS FOR THREE PACKINGHOUSES IN FLORIDA
(A) Total dissolved solids (TDS). (B) pH. (C) Turbidity. (D) Chemical oxygen demand (COD).

The pH was maintained from 6.0 to 7.0, free chlorine started at 34.5 and varied between 25 and 75 mg/L, turbidity increased from 2.1 to 107.0 NTU, COD increased from 147.0 to 519.5 mg/L and ORP increased from 800 to around 900 mV. Chlorine was added approximately every hour during the operation.

Overall Analysis of Water Physicochemical Conditions

Upon initial dumping of tomato bins in all packinghouses, tomatoes plunge deep into the water and then return to the surface. The water acts as a cushion to protect the tomatoes, preventing them from incurring damage. However, this initial plunge may be a concern because the hydrostatic pressure may be very high for a brief period of time resulting in an influx of the wash solution into the tomato stem scar and penetrating any wounds in the tomato flesh (Bartz 1982). When there is sufficient chlorine in the water to prevent cross contamination, as there is early during the operation, this is not a concern. However, as water quality declines and chlorine levels become depleted, water infiltration brings a potentially higher risk of contamination. The data from this survey (Fig. 1) indicate that water quality declined continuously during packinghouse operations, with a significant increase in TDS, turbidity and COD over time ($P < 0.05$) (Fig. 1A,C,D). This is consistent with the observation of accumulated soil, leaves, insects and other debris. Among all packinghouses surveyed, packinghouse I had the lowest TDS, COD and turbidity, whereas packinghouse II operated 4 h longer than the other packinghouses and therefore had the highest TDS, COD and turbidity values at the end of the operation. Our survey also shows that the rate of water quality decline of packinghouse III was comparable with that of packinghouse I, and the increases in TDS and COD in packinghouse III were comparable to those of packinghouses I and II. However, the rate of increase in turbidity in packinghouse III far exceeded that of the other two packing facilities, which is in agreement with the observation that tomatoes delivered to packinghouse III came with more soil and debris, and the bins were dirtier than other two packinghouses. Pearson correlation analysis of all tested parameters was performed. There exists a strong positive correlation between COD and turbidity ($r = 0.841$), and TDS ($r = 0.635$). Since COD measurement usually takes about 2 h (HACH, 2002) whereas turbidity can be determined fairly quickly, the strong correlation found between COD and turbidity suggests that turbidity could be used as an indicator for organic load for tomato packinghouse operations. Similar results were found in our previous studies on leafy green vegetables (Luo 2007; Luo *et al.* 2012).

Free chlorine concentration varied widely among different packinghouses (Fig. 2A,B) as influenced by the specific chlorine dosing protocols and water organic levels. In packinghouse I, chlorine concentration started very high in the beginning of operation and declined steadily over time. In packinghouse III, chlorine concentration was comparatively low, and relatively stable throughout the entire operation. In packinghouse II, the chlorine concentration fluctuated significantly during operation. It was also observed that, as the workday progressed, and the water became more turbid, the maintenance of stable free chlorine residuals became more difficult. Under current tomato harvest operations,

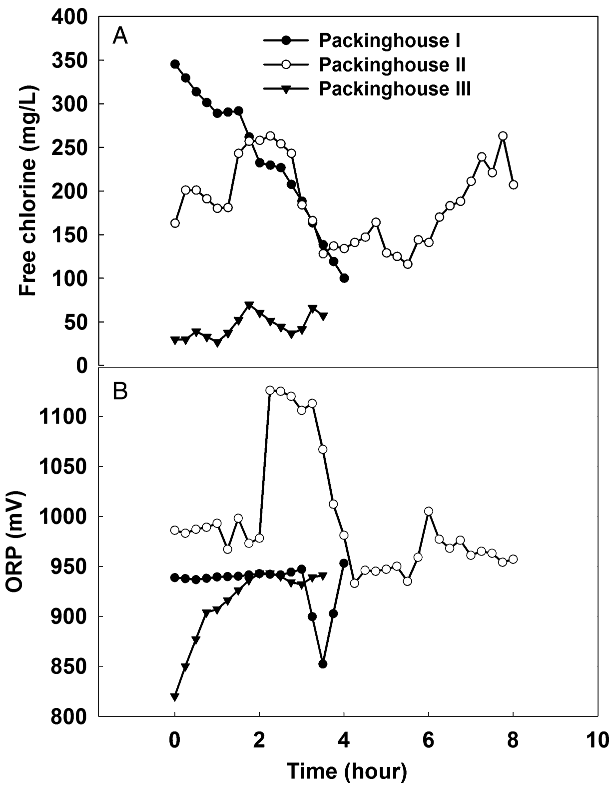

FIG. 2. TOMATO DUMP TANK WATER QUALITY PARAMETERS FOR THREE PACKINGHOUSES IN FLORIDA
(A) Free chlorine. (B) ORP.

soil and organic debris adhered to fruits and containers can be a problem for maintaining free chlorine concentration. Therefore, besides the control of harvest time, prewashing harvest bins, palletized totes and pallet skids can prolong the useful life of chlorinated washing water. Lopez-Velasco *et al.* (2012) reported that water turbidity had a significant interaction with sanitizers and was well correlated with the survival potential of *S. enterica* in the simulated process water. Therefore, filtering out organic matter and debris and reconditioning chlorinated water frequently is essential for maintaining effective sanitation.

Wash water pH levels in these packinghouses differed, ranging from 6.0 to 7.5, and mostly were kept stable except for packinghouse II (Fig. 1B). Water pH in packinghouse II dropped down to 3.5 during a period of approximately 2 h when there were no tomatoes washed (Fig. 1B; 2–4 h) while the citric acid was continuously pumped into the system. Changes in ORP values reflect closely the changes in free chlorine and pH. OPR values are negatively correlated with pH ($r = -0.784$) and positively with free chlorine ($r = 0.354$), although the latter correlation coefficient is quite low (Table 2). The frequency and amount of chlorine addition greatly affected the real-time value of free chlorine and ORP in wash water. Packinghouse III implemented an ORP feedback system that allowed for more accurate adjustment of concentrated chlorine addition. This system, even with the rapidly declining water quality parameters, allowed for the maintenance of low but effective free chlorine concentrations (25–75 mg/L) in the primary dump tank.

CONCLUSION

All three packinghouses differed significantly in wash system configuration, operation protocols, and chlorine monitoring and dosing schemes. However, water quality generally declined significantly over time in all three packinghouse wash systems. This includes a significant increase in COD, TDS and turbidity over time. Free chlorine concentration, pH and ORP fluctuated widely during operations and varied among packinghouses. Despite of these fluctuations and variations, the wash water in all packinghouses surveyed maintained at least 25 mg/L free chlorine or at least 820 mV ORP. In addition, all three packinghouses operated in accordance with T-BMP, with respect to requirements of cleaning dump tanks and changing water daily, maintaining dump tank water temperature at 5.56C above the incoming fruit pulp temperature, and immersing tomatoes no longer than 2 min, and no deeper than two layers of fruits in the dump tanks. Additionally, all surveyed packinghouses complied with requirements to monitor free chlorine concentration, water temperature and pH at start-up and every hour by hand thereafter and to record

TABLE 2. MATRIX OF PEARSON CORRELATION VALUES AMONG WATER PHYSICOCHEMICAL PARAMETERS

Parameters	Free chlorine	pH	ORP	Turbidity	TDS	COD
Free chlorine	1.000	0.093	0.354*	−0.568*	0.008	−0.531*
pH		1.000	−0.784*	0.059	−0.819*	−0.351*
ORP			1.000	−0.111	0.766*	0.247*
Turbidity				1.000	0.282*	0.841*
TDS					1.0000	0.635*
COD						1.000

Asterisk denotes statistical significance at $P < 0.05$.
COD, chemical oxygen demand; ORP, oxidation reduction potential; TDS, total dissolved solid.

these measurements in writing. In each packinghouse, electronically monitored oxidant concentrations of wash water were verified for accuracy against a chemical test that measures free chlorine and pH at start-up and every 2 h thereafter. Electronic monitoring of water temperature and pH were also checked by appropriate verification procedures. The differences seen among the three packinghouses indicate that by standardizing procedures, improvements could be made in the economy and efficiency of the operations.

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