Water consumption and wastewaters in fresh-cut vegetable production

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Controlled water use is an important component of sustainable fresh-cut vegetable production because of limited water resources, and also for controlling the quality of wastewater re-used in vegetable processing or for irrigating on fields. In our study the water consumption in vegetable processing plants varied from 1.5 to 5.0 m^3 t^{-1} of finished product. In one plant, monitored over three years, almost 90% of water was used for washing and rinsing of vegetables, but more than 90% of the organic load of the wastewater was generated from the processing stage. The results including organic load and the microbial quality of the wastewaters showed that the wastewater should be treated before re-use. Separate treating of wastewaters from processing stage is recommended. Pre-treatment of wastewater using precipitation chemicals and sedimentation in basins decreased the organic load and total solids in the water, allowing further treatment of the waters.

Key words: Vegetable processing, processing plants, water re-use, microbiological quality, precipitation, sedimentation

Introduction

The food industry is characterised by a high consumption rate of high quality water per ton of food product (Casani et al. 2005). A large volume of water is used in the processing of fresh vegetables, for removing soil from unpeeled vegetables, for cleaning, rinsing and cooling of processed vegetables and also for cleaning of different environmental surfaces in the processing plants. These washing and sanitation operations are a major concern in reducing the total water consumption within the fresh-cut processing sector (Ölmez 2013). Many food processing plants are already re-using water and looking for ways to increase the re-use of process water, because of the limited availability and cost of clean water and also due to wastewater discharge costs (Hancock 1999). In many countries re-use of water during food production and processing is expected to increase (Kirby et al. 2003), and cleaning and treatment of the wastewater is therefore important in order to guarantee sufficient quality and safety of the recycled water used in the handling of fresh vegetables.

Along the processing line, the microbiological quality of the process water is a very important factor affecting the quality, safety and shelf-life of the product (Ölmez and Kretzschmar 2009, Määttä et al. 2013). The Codex Alimentarius (FAO/WHO 2003) also states that if water is circulated for re-use, no risk to the safety and suitability of food should be caused. The wastewater resulting from vegetable processing contains a high concentration of organic matter, including both soluble and particulate components. According to Hamilton et al. (2005), the high levels of organic matter in wastewater could potentially encourage the growth of plant pathogens. Contaminated water can result in the transmission of many disease agents and cause outbreaks in countries world-wide (Kirby et al. 2003). In addition to microbiological risks, the high amounts of organic matter in the wastewater are challenging for the efficient operation of wastewater treatment systems (Derden et al. 2002). Biological wastewater treatment processes are required for wastewaters with high organic concentrations and flow rates (Hancock 1999).

There are few studies available examining the use of wastewaters from vegetable processing to irrigation. Islam et al. (2005) observed that *Escherichia coli* O157 : H7 present in soil or irrigation water contaminated the carrots grown on the field. Survival of the bacteria in the soils and in the carrots was similar irrespective of the source of the bacteria, manure or contaminated irrigation water. Ibenyassine et al. (2007) observed that the microbiological quality of vegetables irrigated with untreated wastewater was poor. According to Campos (2008) it is essential to control the microbiological quality of wastewaters used in irrigation. The WHO guidelines for wastewater use in agriculture provide a framework for wastewater quality for use in crop production (WHO 2005). In the Mediterranean countries there are unequal criteria, although the need for sharing common regulations for developing water re-use standards has been acknowledged (Brissaud 2008). Mebalbs and Hamilton (2002) studied carrot

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(*Daucus carrota*) wash waters and their re-use. In their study, field and post-harvest plant pathogens were present in wash water. Some risk that water re-use for washing or irrigation could redistribute the spores of pathogens either on the product after harvest or on growing plants in the field was observed. According to Ganoulis (2012), in the control of the risks associated with the wastewater reuse in general, risk data of maximum pollutant concentrations have a significant role. In a risk evaluation study by Mena and Pillai (2008), irrigation water had a significant role in contamination of vegetables. In that study GAP (Good Agricultural Practices) were evaluated for the microbiological risk of vegetables, and *Salmonella* was used as an example microbe.

Microbial parameters are not systematically included in the quality assessment of wastewater treatment. The physiochemical quality of wastewater effluents is determined by the presence of disinfection residues, the formation of toxic disinfection by-products and the modification of organic matter, which can harm the environment (Lazarova et al. 1998). A few publications are available concerning formation and hygiene of wastewater in the fresh-cut industry. Hamilton et al. (2005) studied physical, chemical and microbial characteristics of carrot washing waters and re-use of these waters for irrigation or for further washing in Australia. According to their study water should be of sufficient quality to prevent detrimental agricultural and environmental effects. Wastewater from the carrot washing process was generally of sufficient quality to be re-used for washing or irrigation, providing it was managed appropriately. Kern et al. (2006) examined the treatment of recycled carrot washing water in Germany. They recommended separating the settling and aeration processes in order to optimize the wastewater treatment process. Nelson et al. (2007) studied polymeric microfiltration for treating wash waters from a fresh-cut vegetable processing plant. Microorganisms and total solids were decreased in the filtration, and the authors concluded that water could be re-used in the plant examined for removing soil from incoming vegetables.

Fresh vegetable production is a growing production sector. In addition to particular vegetable processing plants (factories), currently also many farms have expanded their operations from farming to processing of fresh-cut vegetables. However, knowledge has been lacking about the water use in different stages of the fresh-cut vegetable process. Likewise, there is need for obtaining information about different waters created in the vegetable processing.

When the water use is monitored and water quality is measured, it is possible to reduce water consumption and wastewater quantity and to improve its quality (Ölmez 2013). Obtaining information about the water use and wastewater production is important for recognizing critical phases for further studies and for risk management, and also for evaluating the need of pre-treatment of wastewater before the re-use of it.

In order to obtain information for effective water use in the fresh-cut vegetable production, and for increasing knowledge for controlling the quality of wastewater used for irrigating on fields, the objective of our study was to determine the quantity and the microbial, physical and chemical quality of the wastewaters generated from different steps of process lines at fresh-cut vegetable processing plants. The water use in different vegetable processing plants and the amounts of water consumed and discharged at specific steps of the processing line were determined. Water treatment in two wastewater basins and the effectiveness of the precipitation chemicals in the laboratory were also studied. Finally, the implications for saving and reuse of the wastewaters were discussed and potential means for risk management from the point of view of process waters and wastewaters in the vegetable processing plants were suggested.

Material and methods

Plants (fresh-cut vegetable processing facilities)

Four different processing plants were examined in Finland (Fig. 1). In the vegetable washing plant (A) the examined vegetable raw material, carrots, and potatoes (*Solanum tuberosum*), were washed using a washing basin and a polishing and washing drum. The volume of the washing basin was 20 m^3 and that of the washing drum 5 m^3. After washing vegetables were packed. In the plant B carrots were washed in washing drums and then polished. Processed carrots were cut and peeled by abrasive- and knife-peeling. The volume of the washing drum was 5 m^3. In the plant C carrots and other root vegetables were washed in the washing drums, volume 5 m^3, peeled by knife-peeling and packed. The processing plant (D) included rinsing of washed vegetables, peeling of carrots processing (cutting) of lettuce (*Lactuca sativa* var. *capitata*) and other vegetables and also packing. Lettuce was washed in the two basins both having a volume of 800 litres. Carrots were peeled with a knife-peeling machine (D2), after which they were washed, sliced/grated and packed. Lettuce was cut with a lettuce cutter, washed, centrifuged and packed (D3). As presented in Figure 1, three washing processes (A1, B1, C1), three carrot peeling processes (B2, C2, D2) and one lettuce process (D3) were examined in these companies. Production inputs (the amounts of vegetables in the processes) are presented in Table 1.

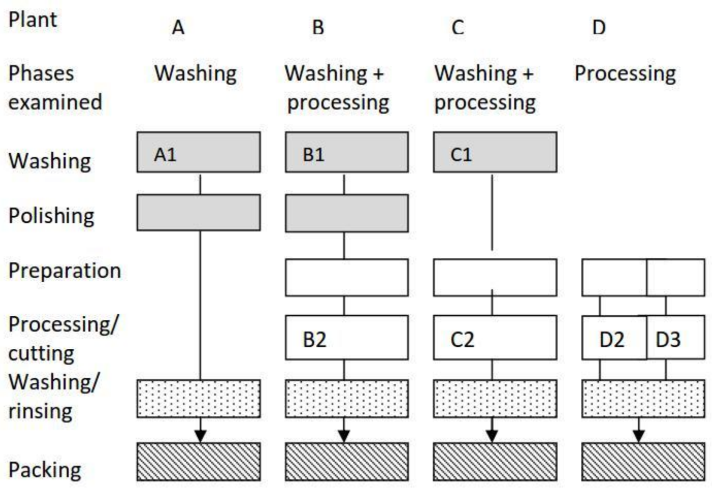

Fig. 1. Phases of the processes in the four vegetable processing plants examined. In plant A the washing phase (A1), in plants B and C the washing (B1, C1) and processing phases (B2, C2), and in plant D the phases of carrot (D2) and lettuce (D3) processing were examined.

Water consumption, sampling

Water consumption was measured in four points: water entering the washing machine, water to processing, water used by pressure washers, and overall water use in the production. Consumption was measured by water meters (Model GSD, B-meters) during a four-week period in 2009 in two fresh-cut vegetable processing plants (B, C). Amounts of wastewater were not measured, since it was assumed that all the fresh water used went to wastewater. The concentration of BOD_7 (biological oxygen demand, 7 days) was measured after washing and after processing. In addition the overall organic loading was measured. The volume of each sub-sample was 1 litre, 7–9 subsamples were taken daily, after which the sub-samples of one day were combined. A one litre sample was taken for microbiological analyses and a two litre sample for biological and chemical analyses. Sub-samples were stored in the production plant (temperature <15 °C), transferred to a cool box and sent to the laboratory every evening.

In one company (C) in which vegetables were washed and processed, water consumption was monitored for more than three years 2008–2011. A water meter (mechanical impeller meter, model GSD, B-Meters) was used to measure the total amount of fresh water consumed in the plant. For monitoring the division of water use in the process, four similar water meters were installed at the influents of the washing machine, the peeling machines and two low-pressure washers. Meter readings were taken once a week. Total water consumption could not be measured with these meters, and the residual consumption was defined by deducting the sum of the results of the installed meters from the total amount of fresh water consumed.

Volume and quality of wastewaters, sampling

The microbiological and chemical quality and quantity of wastewater were measured in four vegetable processing lines and in seven points (phases A1, B1, C1, B2, C2, D2, D3 in Figure 1), from which samples were collected twice from every phase during 2009–2011. When wash waters of root vegetables were studied, samples were taken from the outgoing washing water of three points (A1, B1, C1) in the spring of 2009–2011. Samples from carrot peeling phases (B2, C2, D2) were taken from the wastewater of the peeling machine. Samples of the process water of lettuce (D3) were taken after washing of the lettuce batch. No decontamination was used in the processes examined. The volume of each sub-sample was 0.5 l. The sub-samples were collected during one working day (between 7 a.m. and 16 p.m.), once per hour, resulting in 9–10 samples per day. The sub-samples were then combined and a two litre sample was taken to the laboratory. Samples were kept in the refrigerator before microbiological and chemical analysis.

Sedimentation of wastewater in basins, sampling

Wastewaters from a root vegetable washing plant (A) and a carrot processing plant (B) were piped to treatment basins. Wastewater from the root vegetable washing plant (A) was led to two basins, which were located in series. The volume of the first basin (with mixing) was 110 m^3 (length 10.8 m, width 6.0 m, depth 1.7 m) and that of the second was 90 m^3 (length 10.6, width 5.0 m, depth 1.7 m). After sedimentation the wastewater was led to a ditch. The volume of the carrot processing wastewater basin (B) was 8000 m^3 (length 50 m, width 40 m, depth 4 m). Water was collected to the basin during winter and spread on fields during summer. The quality of wastewater in the basins was studied. The samples were collected twice, in April and in August 2011, from five different points: incoming wastewater to the basin, the surface, middle and ground of the basin and the basin egress. The samples were taken by sucking water from the defend sampling depths with an electric pump. Total solids, biological oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus and nitrogen, *E. coli*, coliform bacteria, faecal coliforms, enterococci, *Yersinia enterocolitica* and *Y. pseudotuberculosis* were analysed.

Precipitation chemicals

The efficiencies of three precipitation chemicals to precipitate solid and organic matter from vegetable washing waters (A) and vegetable processing waters (C) were tested in a laboratory. The chemicals tested were ferrisulphate ($Fe_2(SO_4)_3$, PIX-115, Algol Chemicals), polyaluminium chloride ($Al_n(OH)_mCl_{3n-m}$, Eka WT91, Eka Chemicals), and aluminium sulphate ($Al_2(SO_4)_3$, 33%-solution, Tamro). Half-litre samples were taken and mixed with the chemicals in half-litre bottles. The supernatant was removed with a pipette, after which samples of 2 ml were transferred to the COD measurements. Precipitation was monitored by visual estimation for two hours and by measuring COD of the supernatant (Hach Lange cuvette test LCK314). For investigation of optimum dosage the precipitation chemicals were tested in dilutions of 0, 1:2000, 1:1000 and 1:500 (water control and 0.05, 0.1 and 0.2%-solutions). The tests were performed at the room temperature.

Analysis methods

Microbiological analyses of *E. coli*, coliform bacteria, faecal coliforms and enterococci were carried out at the laboratory of MTT Agrifood Research Finland, and chemical and *Yersinia* analyses at the Water Protection Association of the River Kokemäki laboratory (KVVY). *Yersinia enterocolitica* and *Y. pseudotuberculosis* were measured by a real-time PCR LA517H method (Thisted Lamberz et al. 2008a, b). Water samples were filtered through a Millipore 45 µm filter for determination of faecal coliforms and both presumptive *E. coli* and coliforms. Faecal coliform bacteria were cultivated on m-FC agar (Labema), incubated at 44 °C for 24 h. *E. coli* and coliforms were cultivated on Harlequin™ *E. coli*/coliform agar (LabM Ltd) and incubated at 37 °C for 24 h. On the Harlequin medium, blue-purple colonies were counted as presumptive *E. coli* and all blue-purple and magenta colonies were counted as presumptive coliforms. Heterotrophic plate counts were analysed by the pour plate method on R2A agar (LabM Ltd) and incubated at 30 °C for 3 days. Sulphite-reducing clostridia were determined according to the European Norm on self-made media SFS-EN 26461-2 (1993) and incubated in an Oxoid anaerobic jar. Enterococci were cultivated on KF streptococcus agar (Difco), and colonies were confirmed with 3% H_2O_2 SFS-EN 7899-2 (2002). Total solids were measured by SFS-EN 872 (2005), total phosphorus by SFS-EN ISO 6878 (2004) modified, and total nitrogen by SFS 5505 (1988) modified methods. COD_{Cr} was analysed by the ISO 15705 (2002) method and BOD_7 (ATU) by the SFS-EN 1899-2 (1998) modified.

Results

Water consumption

The total water consumption was highest in the plants in which vegetables were processed (plants B and C) and lowest in the plant where vegetables were washed and packed (A). In the plants examined the total water consumption varied between 1.5 and 5.0 m^3 t^{-1} of finished product (Table 1).

Table 1. Total water consumption in the different kinds of processing plants A-D.

Plant	Operation of the plant examined	Total amount of raw material treated	Range of volume m^3 t^{-1} (finished product)
A	Washing of root vegetables	6000 t of carrots, 3000 t of potatoes	1.5–3.0
B	Washing and processing of carrots	5000 t washed and packed, 5000 t washed and processed	2.0–5.0
C	Processing of vegetables	6500 t of carrots and other root vegetables washed and peeled	3.5–5.0
D	Production of vegetable salads	500 t of lettuce and small amounts of other vegetables washed and cut	2.2–3.2

Water consumption of the vegetable processing plant (C) monitored over three years. A four week sliding average of water consumption over the three years period is presented in Figure 2. Water was used mainly for the washing and rinsing of vegetables. Water consumption was divided into four categories: washing (30%), low pressure cleaners with separate measurement of consumption (14%), processing (42%), and washing of premises and machines (13%). Water consumption in washing varied from 3.5 to 212 m^3d^{-1}, that of pressure cleaners from 15.8 to 47.5 m^3d^{-1}, in processing from 22 to 105 m^3d^{-1} and in washing of premises from 0.1 to 83 m^3d^{-1}. The total water use and also the use of water for different purposes varied considerably between the months according to the season, processing volumes, quality of the raw material etc. When water consumption was compared between the periods 7/2008–7/2009 and 7/2009–7/2010, consumption had decreased by 5%. During the next period 7/2010–7/2011 the consumption decreased a further 10%. Reduced consumption was achieved in the washing of vegetables, which was made more effective by changing water feeders and monitoring water consumption with water meters.

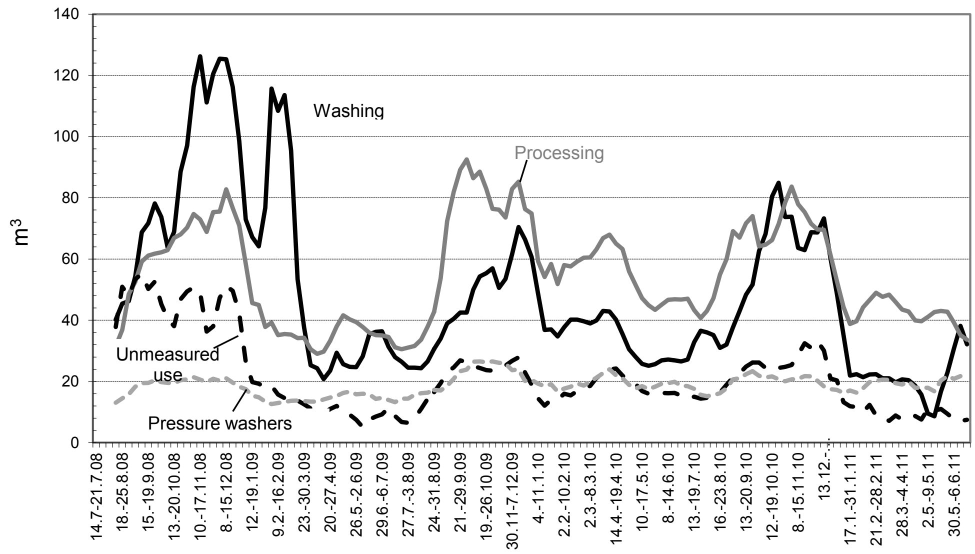

Fig. 2. A four week sliding average of water consumption during three years in the vegetable processing plant (C), in which root vegetables were washed, peeled and packed.

Volume and quality of wastewater

The volume and organic matter content of wastewater were measured in two plants (B and C) in 2009. The total volumes of wastewater from the washing and polishing phases (means 38% and 43%), and from peeling and rinsing (45% and 48% in plants B and C, respectively) were rather similar in both plants. However, most of the biological load of the wastewater, 90% (plant B) and 94% (plant C), was generated from the processing stage, peeling of root vegetables (Fig. 3). In the peeling process most of the organic loading (80%) was generated from the peeling machines (abrasive and knife-peeling).

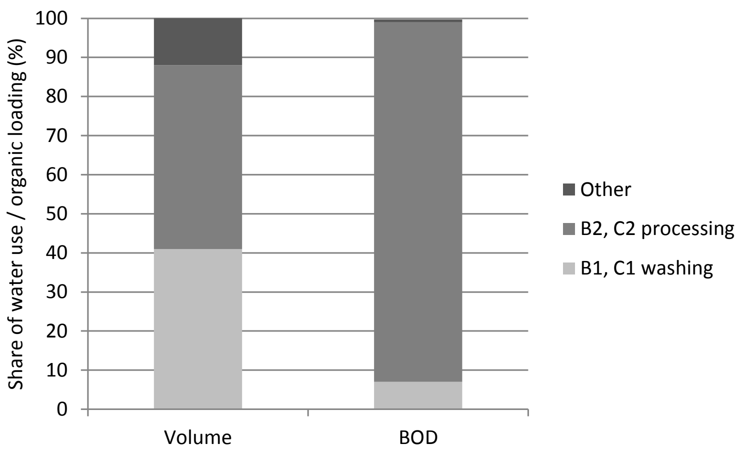

Fig. 3. Division of the mean volumes and mean BOD_7 of wastewaters in two vegetable processing plants (B, C). Washing = water used for cleaning the vegetables before processing; processing = water usage in the processing phase. Other = water used for cleaning the premises and other occasional usage.

The chemical and microbiological quality of wastewater was measured from three phases (washing A1, B1, C1, processing B2, C2, D2 and processing of lettuce D3) (Table 2). The concentration of total solids (TS) in the wash water of root vegetables (A1, B1, C1) was rather high (mean 10 g l^{-1}), whereas it was only 2.4 g l^{-1} in the processing waters of root vegetables and 0.05. g l^{-1} in processing waters of lettuce. The concentration of organic matter (BOD_7) in the wastewater generated from a carrot peeling machine (B2, C2, D2) was high (mean 14 g l^{-1}), as were the concentrations of total phosphorus and nitrogen (46 mg l^{-1} and 220 mg l^{-1}, respectively). Both in the vegetable washing waters (A1, B1, C1) and in the lettuce waters (D3) the concentrations of organic matter were low (1.1 and 0.5 gl^{-1}, respectively).

Levels of *E. coli*, coliform bacteria and enterococci were similar in wash waters of root vegetables (A1, B1, C1) and in waters from a carrot peeling machine (B2, C2, D2) (Table 2). *Yersinia enterocolitica* was found in all these samples. The levels of coliform bacteria, faecal coliforms and enterococci were somewhat higher in washing water of lettuce (D3) than in wash waters of root vegetables and waters from a carrot peeling machine (Table 2).

Table 2. Means and ranges of the quality parameters of wastewaters in the washing (A1, B1, C1), and processing phase (B2, C2, D2), N=6, and processing of lettuce (D3), N=2. Samples were taken after the washing period, after the peeling machine and after the washing of lettuce. Samples were mixed samples of one week.

Parameter	Washing		Processing		Processing of lettuce		Unit
	Mean	Range	Mean	Range	Mean	Range	
TS	10. 0	4.6–18.9	2.4	1.3–4.3	0.05	0.04–0.07	g l^{-1}
BOD_7	1.1	0.4–1.7	14.3	6.3–24.0	0.50	0.46–0.54	g l^{-1}
COD_{Cr}	5.2	4.4–5.9	22.3	9.0–39.0	0.7	0.6–0.8	g l^{-1}
Total P	16	13–19	46	30–58	3.0	3.0	mg l^{-1}
Total N	77	68–92	220	120–360	13	12–13	mg l^{-1}
E. coli	3.5	3.1–3.7	-	<2.7–3.6	3.2	2.9–3.5	log cfu (100 ml)$^{-1}$
Coliform bacteria	5.9	4.9–6.5	5.4	4.5–6.4	6.5	6.0–7.0	log cfu (100 ml)$^{-1}$
Faecal coliforms	3.9	2.3–5.5	4.3	3.8–5.4	6.8	6.8	log cfu (100 ml)$^{-1}$
Enterococci	2.6	1.9–3.4	2.8	2.0–3.6	3.2	3.2	log cfu (100 ml)$^{-1}$
Y. enterocolitica	+	+	+	+	-	-	

+ = found, - = not found

When the amounts of sulphite-reducing chlostrides were analysed from washing waters of lettuce (D3), the result was below the detection limit, <5 cfu (100 ml)$^{-1}$. *Yersinia pseudotuberculosis* was analysed in phases A1, B1, C1, B2, and C2, but was not detected in any sample analysed.

Sedimentation of wastewater in basins

When wastewater of plant B was present in the basin without any mixing, it was anaerobic, and most of the total solids, organic matter and nutrients of the wastewater were located in the ground of the basin (0 – 0.5 m layer from the bottom). None of the microorganisms measured were detected in the wastewater in the middle or in the ground of the basin (Table 3). In the basin of carrot-peeling wastewater (plant B) the concentrations of total solids, organic matter and nutrients were lower in the surface of the basin (0 – 0.5 m from the top of the basin) than in the ground.

Wastewater of root vegetables (plant A) was piped to two basins (110 m^3 and 90 m^3) in order to precipitate the solids and the organic matter (Table 4). Reduction of total solids was 60%. Reduction of BOD_7 was 27%, COD 48%, total phosphorus 43% and total nitrogen 63% in the wash water in the basin (plant A). Concentrations of microbes were at the same level in the incoming water and in the egress of the basin. The pH of the wastewater was between 5 and 6.

Table 3. The quality of wastewater from carrot peeling (plant B) in a wastewater basin, V = 8000 m^3. Results are means of two samples.

Parameter	Sampling site					
	Incoming water	Basin surface	Basin middle	Basin bottom	Basin egress	Unit
TS	1.3	0.2	0.1	2.0	0.3	g l^{-1}
BOD_7	6.5	3.4	3.1	6.8	5.0	g l^{-1}
COD_{Cr}	9.7	5.0	5.5	11.0	7.1	g l^{-1}
Total P	35	18	17	43	13.5	mg l^{-1}
Total N	68	30	26	180	33.5	mgl^{-1}
E. coli	2.5	<1	<1	<1	<1	log cfu (100 ml)$^{-1}$
Coliform bacteria	3.2	2.0	<1	<1	<1	log cfu (100 ml)$^{-1}$
Faecal coliforms	2.3	2.5	<1	<1	<1	log cfu (100 ml)$^{-1}$
Enterococci	3.8	<1	<1	<1	<1	log cfu (100 ml)$^{-1}$
Y. enterocolitica	-	-	*	*	*	

- = not found
*= not analysed

Table 4. The quality of wastewater basins of carrot washing water (plant A). Volumes of the two basins were 110 m^3 and 90 m^3.

Parameter	Measurement site				
	Incoming water	Basin 1 entry	Basin 1 egress	Basin 2 egress	Unit
TS	10	7.7	3.5	4.0	g l^{-1}
BOD_7	1.1	*	*	0.8	g l^{-1}
COD_{Cr}	5.2	*	*	2.7	g l^{-1}
Total P	16	*	*	9.2	mg l^{-1}
Total N	77	*	*	28.5	mg l^{-1}
E. coli	3.7	*	*	<4.2	log cfu (100 ml)$^{-1}$
Coliform bacteria	6.4	*	*	6.6	log cfu (100 ml)$^{-1}$
Faecal coliforms	3.6	*	*	4.5	log cfu (100 ml)$^{-1}$
Enterococci	3.4	*	*	2.3	log cfu (100 ml)$^{-1}$
Y. enterocolitica	+	-	*	*	

+ = found
- = not found
* = not analysed

Precipitation chemicals

According to visual estimation the precipitation chemicals tested (ferrisulphate, aluminium chloride and polyaluminium sulphate) made the precipitation of solids clearly faster and more effective than without the use of chemicals. Chemicals also improved the precipitation of organic matter in the wastewaters. The best results were achieved in the carrot processing water (C) using a 0.05%-solution of ferrisulphate and polyaluminium chloride. With the precipitation chemicals 20–25% of the organic matter was also precipitated. When the wastewater of vegetable washing (A) was examined, the best dosages of aluminium sulphate and ferrisulphate were 0.1 and 0.05% solutions, respectively. With the precipitation of vegetable washing water about 80% of organic matter was precipitated (COD was reduced from 2700 to 500 mg l^{-1}).

Discussion

In our study water use was 1.5–5.0 m^3 t^{-1} of finished product in the vegetable processing plants. A large amount of water was generated from the washing and processing phases, although most of the organic loading (90%) was generated from vegetable processing. According to Ölmez (2013), water consumption in the fruit and vegetable processing industry is in the range of 2.4–11 m^3 t^{-1}. In Finland, water is usually taken from the plant's own well, but municipal water is also used. The water volume from own wells is not usually measured and water meters are not installed. Measuring the overall water consumption, including the water taken from the plant's own well, is important because it provides information about the total water use and wastewater formation in the process and in its different parts. This knowledge is important when the re-use and/or purification means of wastewater are planned. Controlled and efficient water use is an important component of sustainable production.

Water use could be decreased by re-using water in the washing of root vegetables. Reducing water consumption can also lead to more concentrated wastewaters. Pretreatment of wastewaters in basins and the use of precipitation chemicals will decrease the concentrations of physical and chemical substances in the wastewater. In our study precipitation chemicals were not used in the basins. However, in plant A the size of particles in basin 2 was too small to allow occurrence of any further precipitation. Precipitation chemicals could enhance the precipitation. In the present study most of the organic loading was formed from the peeling phase and from the peeling machine. The most of the organic loading was in soluble form. If this phase was treated separately, the rest of the wastewaters could be reused and treated easier. Vegetable peeling wastewaters of high volume and high soluble organic loading should be treated biologically, in an aerobic or anaerobic treatment plant (Ersahin et al. 2011, Lehto et al. 2009).

We measured BOD of carrot washing water taken after treatment in a sedimentation basin. The BOD_5 value was 670 mg l^{-1}. The reduction achieved by sedimentation was not sufficient according to the Ministry of the Environment of Finland (2011), because the BOD reduction of >80% is demanded in the legislation. These vegetable wash waters should therefore be treated after sedimentation. Our BOD values were higher than those by Hamilton et al. (2005) who stated that the high levels of organic matter (high BOD and COD) in wastewater could potentially encourage the growth of plant pathogens. They measured BOD_5 levels up to 320 mg l^{-1} in wastewaters of carrot washing. Trials testing disease incidence in crops that are irrigated and/or washed with wastewater need to be conducted.

In our study the *E. coli* level was from $5.0*10^2$ to $5.5*10^4$ cfu (100 ml)$^{-1}$ in carrot washing water. However, in Finland wastewaters have rarely been used for irrigation and vegetable wastewaters are hardly ever if at all used for irrigation of vegetable crops. According to the WHO guidelines (2005) the amounts of faecal coliforms should be $<10^3$ cfu (100 ml)$^{-1}$ if water is re-used for irrigation of vegetable crops. Some of our results exceed and some are below the limit value given by WHO. In an Australian study the case of the faecal contamination indicator bacterium *E. coli,* concentrations of up to $2.8*10^3$ cfu ml^{-1} have been detected in wastewaters from carrot washing, which indicates a potential hazard to the consumer if the water is re-used without any decontamination step (Hamilton et al. 2005). In Australia for on-farm food safety for fresh products, the concentration of thermotolerant coliforms in farm irrigation water should not exceed 1000 cfu (100 ml)$^{-1}$ and the concentration of *E. coli* in produce should not exceed 20 cfu g^{-1} (DAFF 2004). More research is needed to examine the effect of different decontamination methods for waters on the quality of process and waste waters in vegetable processing, and more knowledge is needed of the risks involved when wastewater is used for irrigation of fields.

The microbiological quality of wastewaters was on the same level in different phases of root vegetable washing (A1, B1, C1), vegetable processing (B2, C2, D2) and lettuce processing (D3), although the chemical and physical qualities of these waters differed considerably from each other. In lettuce washing waters the levels of microbes were somewhat higher than in the other waters examined, although the levels of organic matter and nutrients were lowest in the lettuce washing water (Table 2). The pH in lettuce washing water was 6–7, which is optimal for most microbes. Lettuce has a large surface area, on which microbes can be attached and from which they can migrate into the washing water. According to this result it is important to avoid circulation of lettuce washing water, or lettuce wash water should be decontaminated if it is circulated. If wash water is disinfected, organic matter should be removed from the wash water before the treatment, e.g. using different kinds of filtration methods, because when organic matter reacts e.g. with chlorine by-products may be formed (López-Gálvez et al. 2010), and decontamination is less effective.

In our study COD in circulated lettuce washing water was 700 mg l^{-1} and the amount of total solids was 50 mg l^{-1}. After washing lettuce with this water, the amount of total aerobic microbes in lettuce raw material was decreased only slightly (from 5.5 log cfu g^{-1} to 5.4 log cfu g^{-1}) and that of coliform bacteria from 3.5 to 3.3 log cfu g^{-1}. Lettuce wash waters were commonly circulated, chilled and re-used for lettuce washing. Luo (2007) studied wash waters of sliced romaine lettuce. Re-use (circulation) of wash water caused a rapid deterioration of water quality as indicated by increase in COD and BOD. The quality of washing water depends greatly on the cleanness of the lettuce washed. The increase was gradual in total dissolved solids and salinity and a dramatic decline of free chlorine level was observed. Chlorine was not used in the present study for disinfection of waters. In the study by Luo (2007) samples were washed with re-used water with a COD level of 1860 mg l^{-1}. The changes in water quality had a significant impact on the finished product quality. According to Hassenberg and Idler (2005) the best means to reduce the mesophilic plate count in lettuce by one order of magnitude was washing with fresh tap water.

In our study *Y. enterocolitica* was found in all samples of root vegetable wash waters. However, *Yersinia* was not detected in wastewater basins, although other microbes were found. *Yersinia enterocolitica* is common in soil and also in most wastewaters. It has also been found from well waters in Finland (Korhonen et al. 1996).

Based on the results of this study, some practical recommendations were listed to reduce water usage and wastewater generation and to decrease organic and chemical loads in the vegetable processing plants:

- Fresh vegetable processes should be designed so that the solids and water are separated, if possible. Maintaining a good level of hygiene (of product, process water and surfaces) is a priority, and must also be ensured when planning water use.

- The last rinsing water can be re-used for washing of vegetables. Clean drinking water should be used in the final rinse.

- Monitoring of water consumption and localization of the main consumption points make it possible to decrease water consumption. Peeling is the most important phase in overall water consumption and organic matter loading.

- Highly organically loaded peeling waters and other waters should be separated from each other, and also treated separately.

- Low temperature of cooling and rinsing water also promotes the quality and shelf life of the vegetable product.

- Pretreatment of wastewaters in basins and the use of precipitation chemicals decrease the concentrations of physical and chemical substances in the wastewater.

Conclusions

In the vegetable processing plants the main volume of wastewater was generated from washing and processing of vegetables, whereas most of the organic load came from the vegetable peeling machine and was more than 90% of the whole organic load of the vegetable processing plant. This information helps to allocate effectively the control operations of water use and quality management to the different steps of the processes in which water is used. Because the total water use in the vegetable processing plants examined and also the use of water for different purposes within a plant varied considerably between the months investigated, the water use should be monitored regularly and the water treatment operations should be adapted to take the seasonal variations into consideration. The organic and chemical loads in the vegetable processing plants can be decreased also e.g. by designing the processes to allow separation of the solids and water, by maintaining a good level of hygiene of product, process water and surfaces, and by treating wastewaters from different processing phases separately. The results of the quality (including e.g. the organic load and the microbial quality) of the waste waters showed that the wastewater should be treated before re-use. Organic loading should be first reduced from the wastewater e.g. by sedimentation and precipitation to allow proper further treatment of the waters. The sludge should be treated (composted, decomposted, lime stabilized, etc.) before use as a fertilizer. The organic load of the pretreated wastewaters is mainly in liquid form and can be removed by aerobic or anaerobic biological treatment processes. In earlier studies some risk that use of waste water from vegetable processing for irrigation could forward pathogens on growing plants in the field or on the product has been observed. Decreasing the amount of organic matter and pathogens in wastewater helps to manage the risk when wastewater is utilized by irrigation.

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