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SURFACE HYGIENE IN VEGETABLE PROCESSING PLANTS: RESULTS OF A REPEATED HYGIENE SURVEY

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Abstract

Minimally processed, fresh-cut vegetables have generally been subjected to various processing steps, e.g. peeling, trimming, cutting, washing and rinsing. Minimal processing can enhance contamination of the vegetables with spoilage and even pathogenic microbes due to direct contact of produce with contaminated products, equipment, water or personnel. Good hygiene of environmental surfaces at vegetable processing plants is thus very important.

The aim of this study was to evaluate whether the improvements made in six vegetable processing plants after earlier hygiene monitoring resulted in a change in overall surface hygiene in these plants.

A total of 2913 surface samples were taken from the vegetable processing plants using different rapid hygiene monitoring methods after cleaning of the processing devices and surfaces.

The results of this repeated survey of surface contamination level indicate that surface hygiene can be improved in these plants. The results of the second monitoring were in general somewhat better those of the previous monitoring. Including all detection methods and all six processing plants, the shares of results classified as good had improved on surfaces in contact with product, machines and on packages. General improvements on conveyor belts were minor. Surfaces of processing equipment have been recognized as potential sources of microbial contamination and recontamination of fresh-cut products. In order to control this contamination, it is important to detect the sources of contamination and true critical points. Vegetable production plants need to continue developing cleaning and hygiene practices, training of employees and self-monitoring of surfaces.

***Key words**: Fresh-cut, Vegetable, Hygiene, Monitoring, Improvement, Cleaning, Microbial quality, Plant.*

1. Introduction

Vegetables are nowadays increasingly refined into different consumer products [2], [3]. This increases the complexity of the processes and generates contamination risks. Outbreaks of foodborne illnesses associated with the consumption of fresh produce have increased [4]. Worldwide consumer awareness and legislative demands have also increased in food production, which has led to significant control measures and safety systems in the food sector [5].

Possible pathogenic bacteria in fresh products can be transferred to surfaces and equipment of a production plant, as well as to washing water of vegetables, and contaminate a whole batch [6]. In addition to other important factors, process hygiene in the production plant environment is an important factor for the microbiological safety and quality of products in fresh vegetable production. Good agricultural, manufacturing and hygienic practices and HACCP-based (Hazard Analysis and Critical Control Point) principles are all important for food safety management [7]. Moreover the Directive 2006/42/EC of the European Parliament and of the Council (EU Machinery Directive) asserts that food machinery must be so designed and constructed that the equipment can be cleaned before each use, and that all surfaces in contact with the foodstuffs must be easily cleaned and disinfected. Potentially all surfaces contacting fresh vegetables, from fields to the consumer, are risk factors for contamination, which can arise from environmental, animal or human sources [8]. Poor sanitation in the plants may also promote contamination of vegetables. Concerning the production phase, important factors causing contamination risks for the products are contaminated surfaces and equipment, personal hygiene, and the processing itself such as cutting, peeling and washing [9]. Several earlier studies have indicated even heavy contamination on environmental surfaces of vegetable processing plants, and also inadequacies in currently implemented

food safety in fresh produce chains, related to insufficient sanitation, hygiene deficiencies and inadequate production practices ([1], [10], [11], [12], [13], and [14]).

This study is a continuation of a previous study by Lehto *et al*. [1]. In the earlier study surface contamination level was quantified after cleaning in six fresh-cut vegetable processing plants. The highest levels of total microbes, yeasts, enterobacteria and β-glucuronidase-positive bacteria (β-gur), were detected on machines such as cutters and peeling machines. High mean values of ATP (adenosine triphosphate) were detected e.g. on packaging surfaces (due to high values of wooden boxes) and on cutters. In the present study the same plants as in the study by Lehto *et al*. [1] were monitored to examine whether the surface hygiene had improved after the enhancements carried out in the companies. After the previous study many improvements concerning the critical points of the processes and the rooms were recommended to the companies. According to qualitative observations, enhancements had been carried out in the plants following many of the recommendations. In keeping with the self-monitoring plans, the personnel of the plants monitor the hygienic level regularly in order to maintain the surfaces at a good hygienic level or even improve it. However, in our studies wider hygiene monitoring was carried out in order to identify critical points on surfaces. On the basis of the results of the repeated hygiene monitoring, the aim of this paper is to evaluate whether the improvements had a detectable influence on surface hygiene in the six vegetable processing plants.

2. Materials and Methods

2.1. Surface and air sampling and hygiene monitoring methods

Six vegetable processing plants were monitored during February 2012 in order to evaluate the hygienic level at different process stages. All plants were the same as in our previous study Lehto *et al*. [1]. All the plants processed carrots and other vegetables from 500,000 kg to 15,000,000 kg per annum. However, the plants differed considerably with regard to the rooms, operations, processes and capacity, as reported in the earlier study Lehto *et al*. [1]. A total of 264 to 696 surface samples were taken from each plant after normal daily cleaning processes by a sampling plan made in advance. Raw material and product (carrot) and process water samples were taken accordingly from every plant and these results are presented in Määttä *et al*. [15].

Processes and the end products were different in every plant ([1], [15]). Most of the measuring points were from surfaces which were in a direct contact with these products. Some objects, e.g. boxes, baskets and tubs, were not in direct contact but they were measured since they could cause contamination of the product. Some of these containers, in which products were collected during the vegetable treatment processes, were often kept directly on floors.

Surface samples were taken using Hygicult® dipslides, which measure the numbers of total microbes, enterobacteria and β-glucuronidase-positive bacteria, yeasts and moulds on surfaces. Both sides of the slides were examined and the mean was presented as the final result. ATP bioluminescence samples were taken by the same person with sterile cotton swabs. The sampling procedure was carried out according to the manufacturer's instructions. The sampling methods are presented in detail in Lehto *et al*. [1].

The evaluation criteria of the results are presented in Table 1.

Results of total microbial counts were evaluated according to a Finnish surface monitoring guide presented by Rahkio *et al*. [16]. Yeast, mould, enterobacterial, and β-glucuronidase-positive bacterial counts were evaluated according to the manufacturer's instructions. The guidelines were the same as in the previous study, presented in Lehto *et al*. [1].

Table 1. Surface hygiene guidelines for total microbes, yeasts, moulds, enterobacteria and β-glucuronidasee-positive bacteria on food processing surfaces (cfu/cm2) investigated using contact plates (dipslides)

Microbial group	Good	Moderate	Unacceptable	Reference
Total microbes	< 2	2 - 10	> 10	Rahkio *et al*. [16]
Yeasts	< 1	1 - 5	> 5	Hakala [17]
Moulds	-/+ (light)	++ (moderate)	+++ (heavy)	Instructions Orion Diagnostica [18]
Enterobacteria	< 0.1	0.1 - 1.1	> 1.1	Instructions Orion Diagnostica [18]
β-glucuronidase-positive bacteria	< 0.1	0.1 - 1.1	> 1.1	

The results were collected in a database. The data was divided into five groups as in the previous study Lehto *et al*. [1] (Table 1). In groups 1, 2 and partially in group 3 (conveyor belts), the surfaces were in a direct contact with the product:

1) Surfaces of machines such as cutters, peeling machines etc.
2) Surfaces in contact with the product, other than machines, including different kinds of table surfaces, chopping boards, knives etc.
3) Conveyor belts.
4) Packages of finished products.
5) Surfaces not in direct contact with products e.g. control panels, indoor environmental surfaces (door knobs, displays of scales, trucks, floors, cleaning equipment).

3. Results and Discussion

3.1 Results

Overall, including all detection methods and all six processing plants, the shares of results classified as good had improved on surfaces in contact with product (from 39% to 60%), on machines (from 22% to 39%) and on packages (from 20% to 32%). General improvements on conveyor belts were minor (from 23% to 25%).

The most obvious reductions of total microbes were observed on machines, on which the numbers of yeasts, enterobacteria and β-glucuronidase-positive bacteria had decreased (Figure 1a and 1b).

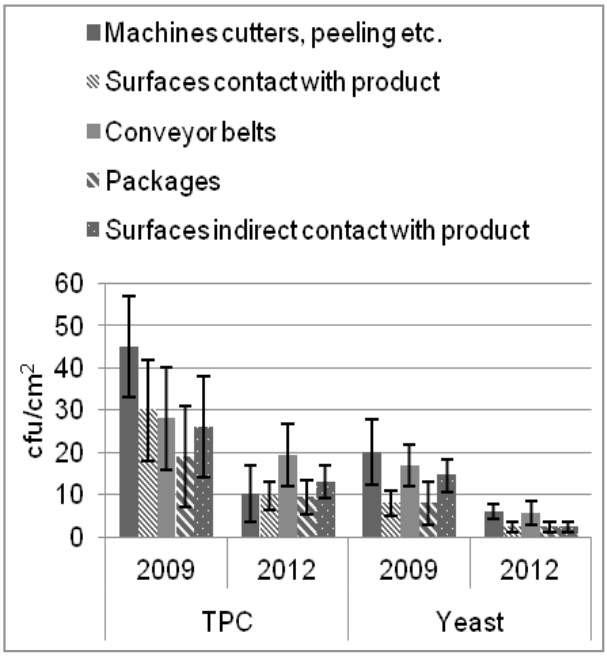

Figure 1a. Mean values (column) and standard errors of means (± SE, bar) of total microbes (TPC) and yeast counts on environmental surfaces in six vegetable processing plants. Results from 2009 are from Lehto *et al*. [1]

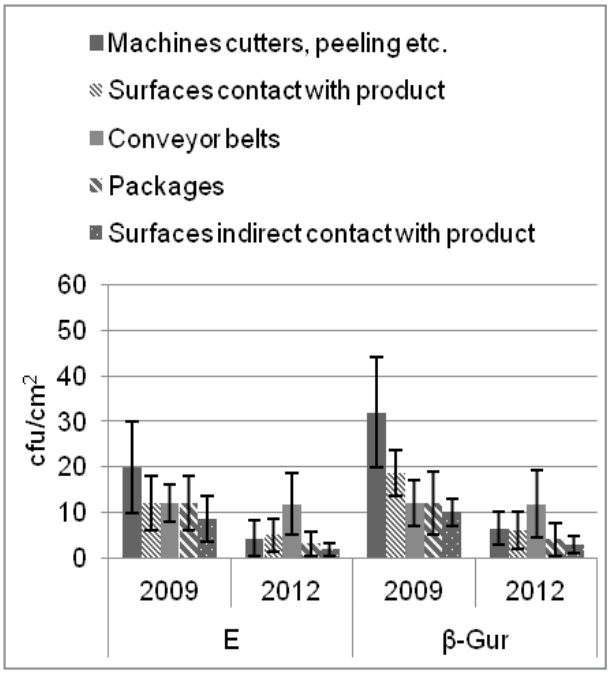

Figure 1b. Mean values (column) and standard errors of means (± SE, bar) of enterobacteria (E) and β-glucuronidase positive bacteria (β-gur) counts on environmental surfaces in six vegetable processing plants. Results from 2009 are from Lehto *et al*. [1]

Similarly, the numbers of all measured microbes on surfaces in contact with product had decreased in 2012 compared to those recorded in 2009. The mean number of total microbes and yeasts on conveyor belts had decreased from the year 2009 to 2012, whereas the numbers of enterobacteria and β-gur had remained almost the same. On packages a decreasing trend was observed in the number of all measured microbes, but taking the deviations into account the reductions were not as clear as on other types of surfaces. This is partly because unlike the other package types, the hygiene of carrot packages had in general declined from 2009 to 2012. Concerning the ATP results of packages, deviations were in some cases great: e.g. the plastic covers of tubs had between 250 RLU and 29000 RLU in 2012, compared with ca. 1200 RLU in 2009, although these are only individual results. The mean numbers of all measured microbes on surfaces in indirect contact with product had decreased in 2012, particularly those of yeasts, enterobacteria and β-gur.

Detailed results of different sampling targets from the year 2012 are presented in Tables 3 - 6. In the case of surfaces in contact with product, the highest numbers of total microbes classified as unacceptable were detected on the surfaces of gloves, plastic boxes, scales, chopping boards, steel washing basins of lettuce and packing boards (Table 2).

Table 2. Hygiene results of surfaces in contact with product. SE = standard error of mean, n = number of measurements, TPC = total microbes, ATP = adenosine triphosphate bioluminescence, RLU = relative light unit, * = not measured.

Sampling target	TPC (cfu/cm²)			Y&F (moulds) (cfu/cm²)				Y&F (yeasts) (cfu/cm²)			Enterobacteria (cfu/cm²)			β-Gur (cfu/cm²)			ATP (RLU)			
	mean	SE	n	mean	min	max	n	mean	SE	n	mean	SE	n	mean	SE	n	mean	min	max	n
Surface of scales	22	13	8	+	-	+++	8	1	0.8	8	11	11	4	11	11	4	2684	67	5300	2
Edge of flushing basin	0.2	0.1	4	-	-	-	4	0	0	4	0	0	2	0.2	0.2	2	871	41	1700	2
Rolls of roll sorter	0.2	0.1	2	-	-	-	2	0.1	0.1	2	0	0	1	0	0	1	10	260	260	1
Surface of chopping board	15	6	12	+	-	+++	12	0.2	0.1	12	1	0.8	6	1	1	6	209	19	480	5
Knife	0.0	0	4	-	-	-	4	0	0	4	0	0	2	0	0	2	449	7	890	2
Steel washing basin of lettuce	13	11	4	-	-	-	4	0	0	4	23	23	2	23	23	2	171	22	320	2
Packing board	12	4	30	+	-	++	30	4	4	30	3	6	14	3	6	14	569	18	3400	11
Metering device	0	0	6	-	-	-	6	0	0	6	0	0	3	0	0	3	727	20	1800	3
Steel surface	2	0.4	24	+	-	+++	24	0.8	0.2	24	0	0	12	0.3	0.3	12	89	8	370	5
Sinks	0.2	0.1	4	-	-	-	4	0.1	0.1	4	0	0	2	0	0	2	21	14	27	2
Washbasin of product	1	0.3	10	+	-	+	10	0	0	10	0.1	0.1	6	0.1	0	6	66	20	160	5
Bagging machine	0	0	8	-	-	-	8	0	0	8	0	0	4	0	0	4	372	49	1300	4
Gloves	68	9	8	++	-	+++	8	23	8	8	35	10	4	53	18	4	1308	240	3000	4
Centrifuge basket of lettuce	0.7	0.4	4	-	-	-	4	0	0	4	0	0	2	0	0	2	287	43	530	2
Inner surface of plastic box	23	8	8	+	-	+++	8	12	7	8	12	11	4	12	11	4	*	*	*	*
Edge of packing board	2	0.5	8	+	-	+	8	0.3	0.1	8	0.2	0.2	4	0.1	0.1	4	267	100	520	3
Brim of a conveyor	4	3	14	-	-	+++	14	0.1	0.1	14	0.3	0.3	7	0	0	7	94	29	150	5

Table 3. Hygiene results of machines (cutters, peelers etc.). SE = standard error of mean, n = number of measurements, TPC = total microbes, ATP = adenosine triphosphate bioluminescence, RLU = relative light unit, * = not measured

Sampling target	TPC (cfu/cm²)			Y&F (moulds) (cfu/cm²)				Y&F (yeasts) (cfu/cm²)			Enterobacteria (cfu/cm²)			β-Gur (cfu/cm²)			ATP (RLU)			
	mean	SE	n	mean	min	max	n	mean	SE	n	mean	SE	n	mean	SE	n	mean	min	max	n
Belt to packing table	15	3	42	++	-	+++	42	1	0.3	42	2.5	2.1	21	3.0	2	21	948	6	160000	12
Foot of the plastic moulding	50	29	4	-	-	+	4	23	13	4	41	39	2	40	40	2	36537	74	73000	2
Belt to bagging machine	2	0.7	12	+	-	+++	12	0.8	0.6	12	7	6	7	7	6	7	122	11	350	7
Sorting belt of washed carrot	41	22	4	-	-	-	4	25	12	4	63	18	2	63	18	2	858	16	1700	2
Belt of whole carrots	15	9	12	++	-	+++	12	0.8	0.6	12	0.9	0.8	6	8	8	6	270	29	750	6
Lifting conveyor of carrots (not peeled	15	5	20	-	-	+++	20	1	0.4	20	1	0.6	10	2	1	10	5192	480	21000	5
Input belt in dirty area	69	8	8	++	-	+++	8	12	7	8	25	12	4	15	10	4	768	768	768	1
Bold belt of peeled carrots	12	4	28	+	-	+++	28	2	1	28	0.8	0.5	14	3	3	14	14181	6	160000	12
Lifting conveyor of peeled carrots	0.4	0.1	40	-	-	++	40	0.1	0.1	40	0.5	0.5	20	0.3	0.3	20	1215	4	20000	20
Gutter, sloping area	6	3	24	-	-	+++	24	0.6	0.3	24	0.3	0.3	12	0.2	0.2	12	196	18	670	10
Rolls of product line	4	2	28	+	-	+++	28	0.2	0.1	28	0.1	0.1	14	0.2	0.1	14	548	4	5100	13
Rolls of packing line	2	0.9	6	++	-	+++	6	1	0.5	6	1	1	3	0.5	0.4	3	260	260	260	1

Table 4. Hygiene results of conveyor belts

Sampling target	TPC (cfu/cm²)			Y&F (moulds) (cfu/cm²)				Y&F (yeasts) (cfu/cm²)			Enterobacteria (cfu/cm²)			β-Gur (cfu/cm²)			ATP (RLU)			
	mean	SE	n	mean	min	max	n	mean	SE	n	mean	SE	n	mean	SE	n	mean	min	max	n
Belt of kronen cutter	52	28	4	-	-	-	4	13	0	4	0.6	0.5	2	0.6	0	2	3910	320	7500	2
Output of knife peeler	14	5	14	++	-	+++	14	1	0	14	0.5	0.4	7	1	0	7	1350	17	6500	7
Inputbelt of knife peeler	68	9	8	++	-	+++	8	9	0	8	13	11	4	13	0	4	4230	320	8500	4
Rolls of knife peeler	11	5	14	-	-	++	14	8	0	14	0.6	0.6	7	0.4	0	7	213	26	680	7
Urchel cutter	0.3	0.1	12	-	-	+	12	0.3	0.2	12	0	0	6	0	0	6	257	42	740	6
Edges of cutters	0.8	0.6	8	-	-	+	8	0	0	8	0.1	0.1	3	0.1	0	3	1591	37	6000	4
Rolls of carbopeeler	69	11	6	-	-	-	6	18	8	6	28	26	3	43	22	3	3328	255	#	3
Hatch of carbopeeler	21	13	8	-	-	+	8	12	7	8	3	1	4	3	1	4	5670	270	16000	3
Knives of Backus cutter	0	0	6	-	-	-	6	15	0	6	0	0	3	3	0	3	70	8	160	3
Inner surface of cap of centrifuge	0.1	0.1	10	-	-	-	10	0.1	0.1	10	0	0	5	0	0	5	302	19	960	5
Base of Kronen centrifuge of lettuce	13	9	10	+	-	++	10	5	4	10	9	9	5	16	16	5	137	73	200	2
Feeding funnel of bagging machine	8	5	11	+	-	+++	11	0.9	0.6	11	0.8	0.8	6	0.8	0.8	6	57	8	130	5
Bagging machine	8	4	20	+	-	+++	20	3	3	20	5	4	10	9	10	9	792	10	4200	10
Feeding funnel of sorter	9	3	32	-	-	++	32	0.8	0.9	32	1	0.3	16	1	1	16	332	20	1600	16

Legend: SE = standard error of mean, n = number of measurements, TPC = total microbes, ATP = adenosine triphosphate bioluminescence, RLU = relative light unit, * = not measured, # = exceeds measurement range.

Table 5. Hygiene results of packages

Sampling target	TPC (cfu/cm²)			Y&F (moulds) (cfu/cm²)				Y&F (yeasts) (cfu/cm²)			Enterobacteria (cfu/cm²)			β-Gur (cfu/cm²)			ATP (RLU)			
	mean	SE	n	mean	min	max	n	mean	SE	n	mean	SE	n	mean	SE	n	mean	min	max	n
Pack of carrots	19	5	16	++	-	+++	16	6	4	16	7	5	8	6	6	8	85	9	270	4
Plastic cover on the tub	1	0.4	7	+	-	++	7	0.9	0.7	7	0.7	0.6	3	2	2	3	14625	250	29000	2
Inner surface of wooden box	17	9	6	+	-	++	6	3	1	6	2	2	3	2	2	3	*	*	*	*
Inner surface of cardboard pack	3	0.6	10	+	-	+++	10	1	0.6	10	0.9	0.4	5	10	9	5	*	*	*	*
Inner surface of plastic box	7	5	16	-	-	+++	16	0.3	0.1	16	6	6	8	0.3	0.2	8	84	5	150	5

Legend: SE = standard error of mean, n = number of measurements, TPC = total microbes, ATP = adenosine triphosphate bioluminescence, RLU = relative light unit, * = not measured.

With some exceptions, heavy contamination with moulds, yeasts, enterobacteria, ß-gur and ATP were also detected from most of the same surfaces. In addition brims of conveyors were heavily contaminated with moulds, and edges of flushing basins, metering devices, knives and bagging machines had significant ATP contamination. However, all these results had in general improved from the previous monitoring [1], when e.g. unacceptable numbers of total microbes were detected on almost all (82%) sampling targets.

Half of the machines had an unacceptable number of total microbes (Table 3), including belts of cutters, parts of knife peelers and carbopeelers and surfaces of lettuce centrifuges. The greatest mean numbers of enterobacteria and ß-gur were observed on knife peelers, carbopeelers with a very coarse surface, centrifuges and bagging machines, and great mean numbers of yeasts on sampling targets of cutters and peelers. As a whole, all these results had in general improved from the previous monitoring, in which all surfaces of machines had high counts of total microbes, yeasts, enterobacteria and ß-gur [1].

Most of the sampling targets of conveyor belts had unacceptable numbers of aerobic bacteria (58%) and high amounts of ATP (58% with over 700 RLU) (Table 4).

Unacceptable average contamination with yeasts, enterobacteria and ß-gur was detected on the feet of plastic mouldings, sorting belts of washed carrots and on input belts in dirty areas. These results were also in general somewhat better than in the previous monitoring [1], in which e.g. 75% of surfaces had unacceptable numbers of aerobic bacteria and 82% had an ATP amount exceeding 600 RLU.

Packs of carrots were the most microbiologically contaminated of the packages, whereas plastic covers (films) on the tubs had the greatest amounts of ATP (Table 5).

These results as a whole were better than in the previous monitoring [1], in which 80% of packages had unacceptable numbers of aerobic bacteria, whereas the corresponding share in the present study was 40%. However, the ATP results of plastic covers on tubs had deteriorated.

Examples of the hygienic level, classified according to Table 1, of conveyor belts in different phases of the production processes are presented in Table 6.

Belts were selected to illustrate the different hygienic areas of the production plants, since unlike e.g. certain machines, they are found in different rooms and production phases in the processing plants in question. However, the numbers of measurements in the washing step were very small. The hygiene of all rooms had improved from 2009 to 2012, despite the result of total microbes in washing sites. According to the mean results of total microbes in 2012 and enterobacteria in 2009, the hygiene level had clearly improved when moving from the dirtiest sites (washing) to the cleanest sites (packaging). In 2009, the difference between the mean numbers of total microbes were the greatest in the dirtiest sites (washing) but hygiene differences between the three room types were less clear than in 2012. On the other hand, in 2012, the results of enterobacteria were similar in the two first phases and somewhat lower in the packaging step.

Table 6. Hygienic level of conveyor belts in different production rooms of root vegetables according to two detection methods. Results are means from all plants.

Room	TPC*				*Enterobacteriae*			
	2009		2012		2009		2012	
	cfu/cm²	n	cfu/cm²	n	cfu/cm²	n	cfu/cm²	n
Washing	53	4	90	2	25	6	5	2
Peeling	35	82	15	84	15	84	5	43
Packaging	37	47	6	56	8	52	3	28

*TPC = total microbes

3.2 Discussion

The main objective of our previous work [1] was to clarify whether cleaning of the processing lines at vegetable processing plants was adequate. In the present study we evaluated whether there had been any improvement in hygiene practices that could be demonstrated to have increased the level of surface hygiene. Vegetables naturally contain high numbers of microorganisms because the cultivation environment harbors high numbers of bacteria, yeasts and fungi [19], which can transfer from soil to vegetables [20] and even inside vegetable cells [21]. Inside the processing plants these microorganisms can in the worst case be forwarded through the different hygiene areas, especially if the areas are not isolated sufficiently.

Microorganisms, biofilms and chemical residues can survive the sanitation process if cleaning and sanitizing procedures have not been strictly followed. It is important to ensure that sanitation has been effective in removing potential pathogens and other food contaminants. The vegetable processing plants that we monitored had a hygiene monitoring program. The processing plants used Hygicult® dipslides for self-monitoring of surface cleanness. In the present study we measured total microbes, enterobacteria and β-glucuronidase-positive bacteria, yeasts and moulds and also ATP bioluminescence on surfaces. ATP bioluminescence is widely used for monitoring the cleanliness of environmental surfaces (e.g. [22], [23], and [24]). In vegetable processing plants it is also important to monitor enterobacteria, moulds and yeast numbers on the surfaces of equipment, machinery, conveyors, etc. [1].

The results of this study indicate that overall surface hygiene in the six processing plants had improved in the measured targets compared to the previous study [1]. The mean numbers of all measured microbes, particularly of yeasts, enterobacteria and β-gur, had decreased in 2012 on surfaces in indirect contact with product in comparison to the situation in 2009. This result is probably at least partly a consequence of the guidelines that were given to the plants after the previous study. In that study most of the bacterial counts measured on the surfaces were unacceptable when using the Finnish surface hygiene guidelines as criteria, although these criteria were considered to be extremely rigorous particularly for the vegetable industry. It is also possible that because the plants had been briefed in hygiene practices after the first monitoring in 2009, they boosted their cleaning before the new hygiene measurements in 2012.

In the present study the results from 2009 and 2012 were compared concerning peeling and packaging sections of the conveyor belts. Both total microbial counts and the counts of enterobacteria had clearly been decreased. In washing sections total microbial counts had increased and the counts of enterobacteria had decreased, but because of the rather low number of measurements this change is not definite. However, these results demonstrate better overall hygiene on the conveyor belts after the first study in 2009. If we evaluate the results of the whole conveyor belt line there is slight decreasing trend in the numbers of total microbes and enterobacteria towards the end of the line. This is essential for maintaining a high level of hygiene throughout the whole process chain. Results concerning the products (fresh-cut carrots) and process waters collected from the six carrot processing plants in 2009 and 2012 have been presented by Määttä *et al*. [15]. In their study washed, unpeeled carrots generally contained the highest total microbial counts (mean 5.5 log CFU/g). The numbers of coliform bacteria and enterobacteria were higher in samples taken from the first steps in the processing line of carrots than in samples taken in later phases of the process. Different hygiene areas [8] should to be separate enough to maintain good hygiene when proceeding to the cleaner areas. A fresh-cut vegetable processing facility should be designed so that incoming raw products never cross paths with finished fresh-cut produce [25]. The efficiency of sanitation depends on the cleanability of the equipment, which in turn is determined by its design [26]. Conveyor belts are among the targets that carry a large amount of organic debris, are often difficult to clean thoroughly and may give rise to biofilm. Regardless of the belt type or material, all conveyor belts are prone to microbial buildup and the subsequent transfer of microorganisms to the incoming product over time. The newer, smooth continuous belts, which can be more easily cleaned and sanitized, are now generally preferred over the older interlocking belts that must be disassembled and manually cleaned and sanitized [27].

Studies in the fruit and vegetable sector have demonstrated the importance of the hygienic design and the sanitation of equipment (e.g., [1], [28], [29], [30]), and the personal hygiene, particularly hand hygiene of workers (e.g., [29], [30], [31], and [32]). Effective training of personnel is an important prerequisite for successful implementation of a food safety management system [33]. Food safety principles should be understood and practiced throughout the entire food chain [34]. Interventions such as improving food handling practices and food safety campaigns are necessary in order to reduce foodborne illnesses [35]. However, Redmond and Griffith [36] reported that despite various efforts in food safety training, unsafe food handling practices are still frequently used. Hence, Jacob *et al*. [34] proposed that effective food safety messages using new media may effectively modify inappropriate human behavior in the food safety system. Enhancement and maintenance of good hygiene in fresh-cut vegetable production requires continuing actions. The current study showed that it is possible to improve surface hygiene in processing plants.

4. Conclusions

- In this study and in our previous study [1], the level of surface hygiene after cleaning in several fresh-cut vegetable processing plants was examined and the critical points in processes and in the premises were identified.

- The current study showed that after enhancement, the hygiene of environmental surfaces in the processing plants was generally improved.

- Processing equipment used in a food plant should be designed in a manner that facilitates cleaning and sanitizing.

- Separating different hygiene areas is essential for preventing cross-contamination in the factories. Appropriate organization of the layout and equipment in the production rooms, efficient cleaning, self-monitoring of the surface hygiene and training of the personnel should also be in continuous focus in the future.

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