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Sanitation of root vegetables

For the treatment of washed carrots to prevent cross-contamination with human pathogens as well as plant pathogens sanitation with chlorinated and ozonated water is recommended. But usually wash and rinsing water in washing plants are loaded with organic substances (chemical oxygen demand (COD)), which limit the sanitation effect of these oxidizing agents. The task of this experimental study was to investigate the remaining inactivation potential of chlorine dioxide and ozone in tap water with increasing COD content.

Keywords
Chlorine dioxide, ozone, COD

Abstract
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Before processing and packaging most outdoor vegetables such as potatoes and carrots have to be extensively washed after harvest, storage or cooling. Nevertheless, the produce should afterwards retain their freshness and crispness to be presented appealingly in retail as long as possible. However, spoilage of products often begins after only a few days at the retailers or at the consumers because mould, bacteria and yeast have been established on the vegetable and proliferate at high rates.

Reasons for high reproduction rates of microorganisms

The high reproduction rates of pathogens may have many different reasons. Field-grown products are not sterile but covered with numerous microorganisms (MO). Amanatidou et al. reported a pathogenic load of 6.4 log CFU per g fresh mass (FM) on untreated carrots [1]. On the field the growth of the different MOs on the produce is balanced in most cases. Spoilage of the product starts as soon as the growth of pathogens predominates that of harmless MOs. This may occur whenever

a) too many detrimental MOs have concentrated in the soils e.g. due to insufficient crop rotation,

b) high soil water content and/or oxygen deficiency favour the growth of detrimental MOs or

c) the vegetable is mechanically injured during harvest, washing or processing.

Wounds facilitate the penetration of MOs into the produce while sap leaking from damaged cells represents a perfect breeding ground for MOs. Mobile bacteria such as *Pectobacterium carotovorum* may be found both on the surface but also inside a produce. If infection exceeds a certain threshold amount of bacteria (10^7 – 10^8 CFU g_{FM}^{-1}) mostly at high temperature and air humidity the outbreak of spoilage is inevitable [2].

For potatoes, for example, estimated economic losses caused by Erwinia infection may range between 50 and 100 million US dollars per year worldwide [3]. In addition moulds such as Thielaviopsis may infect carrots already in the field. Under favourable temperature conditions the mould may grow optimally post harvest; and rapidly, within few days, it exhibits black areas of spores on the surface of carrots stored unrefrigerated.

Risk of consumer disease

Besides phytopathogenic MOs also human pathogenic MOs may be present on out door vegetables. *E. coli*, Listeria and other human pathogens are known to cause diarrhoea, which might be lethal especially for children, and old and debilitated people. There are various pathways the human pathogen MOs can end up on the vegetables. Excrements of animals such as birds, foxes or boars can adhere to the vegetables and can thus, be transported to the packaging plant where it then contaminates the washing machines. Furthermore, in developing countries river water loaded with faeces is often used for irrigation which also may increase the risk of infections and finally diarrhoea. Low hygienic standards during processing, e.g. due to free running animals or diseased employees may be another source of contamination. Furthermore, the use of hygienically objectionable water for washing may be critical. Nevertheless, consumption of totally unwashed vegetables may cause the highest risk of disease. Simply by efficient washing of the vegetables 90 – 99 % of all MOs (1 – 2 log) may be eliminated from the surfaces [4].

Water impurity affects the disinfection

To minimize MOs and to prevent cross-contamination the sanitation of the washing water by chlorination or ozonation is highly recommended. The application of ozonated water for fruit and vegetable washing is reviewed by Khadre et al. [5] who reported an average reduction of total germ count of up to 2 log. However, despite very positive reports in the current literature [6] and although producers and product manuals attested high efficiency the actual effects of such sanitation methods are

Fig. 1

Carrots in drum washer (source Geyer)

often unsatisfactory. When chlorine or ozone in combination with clean tap water are applied under well-defined laboratory conditions, very positive disinfection effects can indeed be observed [7]. However, the effects are only limited if highly contaminated carrots or potatoes are treated or if the water contains large amounts of organic compounds.

Hence, the aim of this study was to analyse the actual inactivation potential of chlorine dioxide and ozone in water that remains when this sanitation treatment is applied to *Pectobacterium carotovorum* and *Escherichia coli* suspended in tap water loaded with different COD concentrations. In sewage technology the degree of contamination of water with organic compounds is generally expressed as the chemical oxygen demand (COD) which indicates the mass of oxygen (in mg l^{-1}) that is required to fully oxidize and, thus, eliminate the organic compounds solved in one litre of waste water. As an example, the maximum permissible organic load of vegetable washing water to be passed into the on-site preflooder is fixed at a COD of 110 mg l^{-1} which corresponds to about 1.5 g fresh carrot. Typically, the COD of washing water in a standard carrot washer is larger than 1000 mg l^{-1} (**figure 1**).

Materials and Methods

Ozonated water was generated using the 'Bewazon 1' ozone generator (0.02 g O_3 min^{-1}, BWT Water Technology Ltd., Schriesheim, Germany). The temperature of the ozonated water was set to 10°C using a thermostat 45 (Haake, Karlsruhe, Germany). To generate a chlorine dioxide solution 3.85 g salt (DK DOX^R component 2, Dr. Küke GmbH, Hannover, Germany) was solved in 250 ml component 1 (DK DOX^R aktiv, component 1) and stored at 30°C for 24 h. The resulting solution contained an active chlorine dioxide concentration of 800 to 1200 mg l^{-1}.

Ozone and chlorine dioxide concentrations were measured with a LASA^R 2plus photometer applying the respective chlorine/ozone cuvette test (Dr. Bruno Lange GmbH & Co., Düsseldorf, Germany).

Fresh carrots yielding a mean COD of 70 mg per g fresh mass were mashed using a hand blender and the resulting puree frozen. Aliquots of this carrots mash (0.1 to 10 g l^{-1}) were mixed with *P. carotovorum* (DSMZ 30168) or *E. coli* (DSMZ 1116) suspension (10^4 to 10^6 cfu ml^{-1}) in 100 ml volumetric flasks. The flasks were filled with chlorine dioxide solution (1 ppm free Chlorine) or ozonated (up to 4 ppm ozone) water until the calibration mark. The resulting mixtures were stirred for 5 min and finally plated (Mac-Concey-Agar plates, Merck, Darmstadt, Germany) and incubated at 37°C (*E. coli*) or 30°C (*P. carotovorum*) for 2 d. All experiments were performed in repeated determination and repeated several times.

Results

The disinfecting effect of chlorine dioxide was annihilated at 140 mg l^{-1} COD in *P. carotovorum* solution and at 70 mg l^{-1} COD in *E. coli* solution. The sanitation effect of ozonated water was even more affected by organic compounds than of chlorine dioxide. The disinfection proved to be ineffective at 50 mg l^{-1} COD (0.7 g mashed carrots per litre) in *P. carotovorum* solution and at 35 mg l^{-1} COD in *E. coli* solution (**figure 2 and 3**).

Discussion

The results show that already lowest concentrations of organic matter in the washing or rinsing water (0.5 – 2 g carrot 35 – 140 mg l^{-1} COD) of vegetable processing plants may inhibit or annihilate the effects of the sanitation treatments. It is highly probable, that the strong oxidizing agents initially react with the solved organic matter thus losing the ability to influencing bacterial growth. Furthermore, the study pointed out that a minimum contact time is needed to guarantee the sanitation effect. In addition, the solubility of ozone in water is limited and decreases significantly with increasing temperature [8]. Therefore, ozonated water is less practical for this application. By contrast, chlorine dioxide solution may be suitable for wash water sanitation at higher concentrations. However, it is associated with a typical odour of chlorine already at low concentrations.

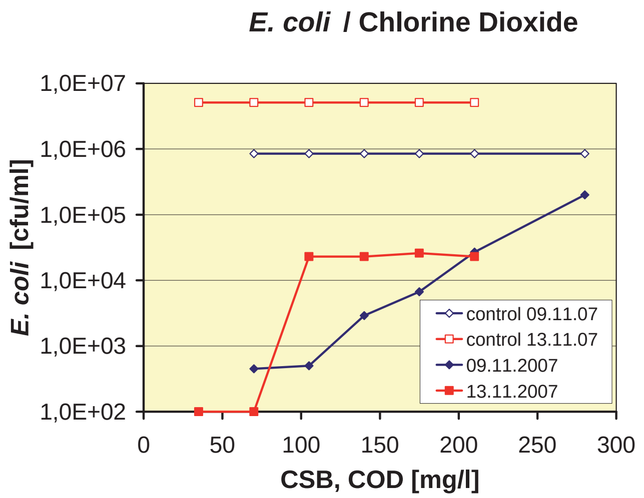
Conclusions

The sanitation effect of oxidizing agents such as chlorine dioxide and ozone dissolved in water to minimize the MOs load on fresh vegetables is limited.

To guarantee a high quality of fresh vegetables good hygienic standards in the field, crop rotation and optimized cultivation regimes are essential. In processing and particularly during washing the application of clean, unpolluted water, frequent and regular water exchange and fixed cleaning cycles including accompanying documents are recommended.

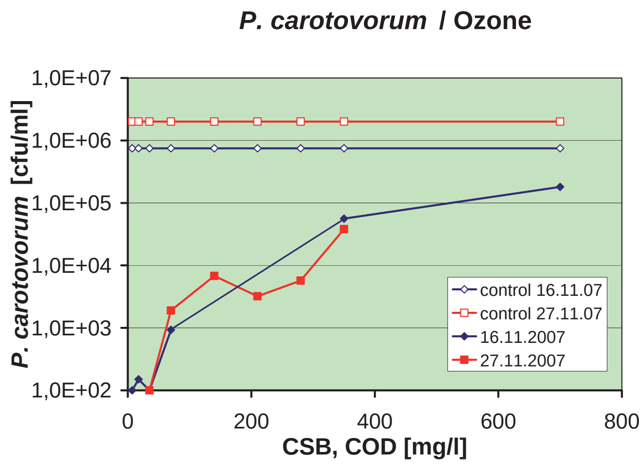
Following these recommendations the application of disinfecting agents is not necessary.

Fig. 2



Inactivation of E. coli in chlorine dioxide water (1 ppm free chlorine) depending on the COD in relation to the control

Fig. 3



Inactivation of P. carotovorum in ozonated water (< 4 ppm free ozone) depending on the COD in relation to the control

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