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MINIMAL PROCESSING OF VEGETABLES

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Abstract

Due to rationalization of production and utilization of peeling waste, it is reasonable to aim at the centralized peeling of vegetables and potatoes. More and more households and catering branches would like to purchase so-called minimally processed, ready-to-use vegetables. Minimal processing of raw vegetables has two purposes. The first is to keep the product fresh, but convenient. The second is to prepare a product with sufficient shelf-life to make distribution feasible within the region of consumption. Methods for improving the shelf life of minimally processed fresh prepared vegetables intended for catering purposes and retail shops are discussed on a general level. The key requirements in the processing are raw material of good quality, strict hygiene and good manufacturing practices, low temperatures during working and storage, gentle peeling, careful washing before and after peeling and suitable additives and packaging materials and methods.

1 INTRODUCTION

For reasons of expense, labour and hygiene, the catering industry aims at purchasing vegetables and potatoes pre-peeled or possibly also sliced, grated or shredded, i.e. minimally processed. Furthermore, more and more households would like to purchase vegetables which are easy and ready to use.

With regard to the rationalization of production and utilization of peeling waste, it is reasonable to aim at the centralized peeling of vegetables and potatoes. However, as a result of peeling, grating and shredding, the vegetable will change from a relatively stable produce with a shelf-life of several weeks or months to a perishable vegetable that has only a very short shelf-life, even only two or three days at chilled temperatures. During the peeling and grating operations many cells are broken, and intracellular products such as oxidizing enzymes are liberated. Simultaneosly the surface of the vegetable is exposed to the air and to contamination with bacteria, yeasts and moulds. Increased respiration activity, microbial activity and enzyme activity are the main reasons for reduced shelf-life. This means that spoilage of raw prepared vegetables may result from degradation of the colour, texture or flavour, as well as from microbial degradation.

Minimal processing of raw vegetables has two purposes. Firstly, it is important to keep the produce fresh, but convenient. Secondly, the product should have sufficient shelf-life to make distribution feasible within the region of consumption (Huxsoll & Bolin 1989). The microbiological, sensory and nutritional (e.g. vitamin C) shelf-life of minimally processed vegetables should be at least 4 - 7 days, but preferably even longer.

The aim of this contribution is to present at a general level some methods for controlling the quality and shelf-life of minimally processed fresh prepared vegetables intended for catering purposes and retail shops. The data and guidelines given are partly based on information from the literature and partly on experience obtained in research projects carried out at VTT Biotechnology and Food Research. The research project 'Processing, packaging and nutritional quality of raw vegetables' has just been completed. The project was financed by the Ministry of Agriculture and Forestry, VTT, the Foundation for the Promotion of Food Production and the Finnish packaging and food industry. In this project the minimal processing of carrot, potato, red beet, rutabega, white and Chinese cabbage, onion and leek was studied.

This paper presents a general picture of which factors are important in successful minimal processing of vegetables. Some factors may seem self-evident, but it is important to remember that minimal processing of vegetables is often practiced by small family companies, where e.g. the importance of hygiene may not always be recognized sufficiently.

2 FACTORS AFFECTING THE QUALITY OF MINIMALLY PROCESSED VEGETABLES

Several factors affect the shelf-life and microbiology of raw prepared vegetables (Zomorodi 1990):

- manufacturing practices
- external and internal quality of vegetable (variety, growth conditions, harvest defects, age etc.)
- washing of vegetables before and after peeling and cutting
- peeling and cutting method
- quality of water used in washing
- additives
- packaging methods and materials
- storage temperature

2.1 MANUFACTURING PRACTICES

The keeping quality of vegetables in processing and storage is significantly dependent on general hygiene. The most important factors for ensuring good hygiene in manufacturing practices have been listed in Table 1.

Table 1. Important factors for ensuring good hygiene in manufacturing practices.

1. Good manufacturing practices
   - Correct arrangement of recieving and storage rooms for raw materials and production rooms in order to avoid cross-contamination
   - Correct arrangement of rest and social rooms
   - Good general maintenance of operation rooms
   - Good personnel training
   - Good personnel hygiene
   - Correct arrangement of waste disposal
   - Inspection and cleaning of pallets and storage rooms

2. Design of equipment and machines
   - Correct choices of equipment materials
   - No dead angles in machines, equipment and elevators
   - Good cleanability of equipment constructions

3. Cleaning and sanitation programme for operation rooms and equipment
   - Daily washing of operation rooms and equipment
   - The following steps are involved in the daily washing:
     * general pre-washing
     * pre-rinsing
     * chemical washing (alkane solution)
     * washing with disinfectant
   - In addition to daily cleaning, operation rooms must be washed thoroughly with a certain frequency, not forgetting places with difficult access.

4. Inspections
   - The plant (also small family plants) must be routinely inspected for housekeeping, pest control, safety, employee dress and good manufacturing practices
   - Equipment must be inspected for cleanliness, safety, maintenance, proper functioning, correct adjustment etc.
   - Operations must be scrutinized for proper procedures, good manufacturing practice, adherence to scheduled process parameters and record-keeping

2.2 THE EXTERNAL AND INTERNAL QUALITY OF VEGETABLES

Vegetables intended for pre-peeling and cutting must be easily washable, peelable and their quality must be first-class. Thus the correct storage of vegetables and careful trimming before processing are vital for the production of prepared vegetables of good quality.

On the basis of experiments carried out at VTT Biotechnology and Food Research it can be concluded that not all varieties of the specified vegetable can be used for manufacturing of prepared vegetables. The correct choice of variety is particularly important for carrot, potato, rutabega and onion. For example with carrot and rutabega, the variety which gives the most juicy grated product cannot be used in the production of grated products which should have a shelf-life of several days. Another example is potato, with which poor colour and flavour become problems if the wrong variety is used.

It is important to realize that each commodity has its own critical factor which determines its shelf-life as a peeled or sliced product. In some cases it is respiration activity, in others it is microbial factors or enzymatic activity or a combination of some or all of these factors. On the other hand, not all commodities are suitable for minimal processing. For example onion and leek cut into small pieces or grated rutabega have a very short shelf-life (only 2 - 3 days), partly due to high respiration activity and probably partly also due to high enzyme activity. It appears that increased enzyme activity is the most important factor reducing the shelf-life of minimally processed products of these vegetables. The significance of enzymes and the methods to prevent their activity should be studied in more detail. Unfortunately, the methods presented in the following do not improve the quality and shelf-life of cut onion and grated rutabega.

2.3 WASHING

If incoming vegetables are covered with soil, mud and sand, they must be carefully washed before processing. The second washing must be done after peeling and/or cutting. For example Chinese cabbage and white cabbage must be washed after shredding, whereas carrot must be washed before grating. Washing after peeling and cutting removes microbes and tissue fluid thus reducing microbial growth and enzymatic oxidization during storage. The microbiological and sensory quality of the washing water used must be good and its temperature low, preferably below +5 °C. Washing water must be removed carefully from the product. The best method appears to be centrifugation. The centrifugation time and speed should be chosen carefully (Bolin & Huxsoll 1991, Zomorodi 1990).

For the reduction of microbial numbers, and to retard enzymatic activity and thus to improve the shelf-life of sensory quality, 100 mg chlorine or 5 g citric acid/l can be used. When chlorine is used the vegetable material should be rinsed (Fig. 1). Rinsing reduces the chlorine concentration to the level of that in drinking water. The effectiveness of chlorine can be improved by using a low pH, high temperature and pure water. By careful washing, the shelf-life of minimally processed vegetables can be improved by several days up to 7 - 8 days (Fig. 1). Even the shelf-life of grated carrot improves markedly if the carrots are washed after peeling with citric acid or chlorine solution before grating (Fig. 2). Washing does not decrease the vitamin content significantly: the main reducing factor is storage time (Table 2).

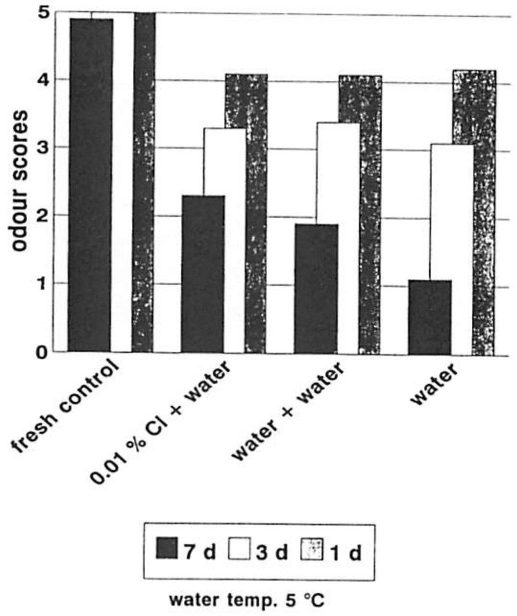

Fig. 1. The effects of various washing methods on the shelf-life of sensory quality (odour) of packed shredded Chinese cabbage stored at +5 °C. Washing was performed after grating (Hurme et al. 1993a).

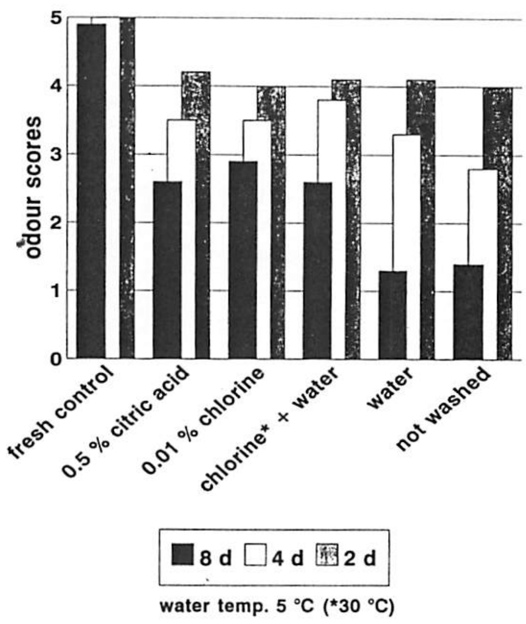

Fig. 2. The effect of various washing methods on the shelf-life of sensory quality (odour) of packed grated carrot stored at +5 °C. Washing was performed before grating (Hurme et al. 1993b).

Table 2. The effects of various washing and storage times on the vitamin C and β-karoten contents of air-packed shredded Chinese cabbage (Hägg et al. 1993).*

Sample/ Washing method**	Vitamin C (mg/100 g fresh weight) 1 day	4 days	7 days	β-karoten (μg/100 g fresh weight) 1 day	4 days	7 days
Fresh cabbage, no washing	14					
Washed cabbage						
1	13	12	9	44	27	20
2	12	12	11	29	24	26
3	12	12	11	23	23	17
4	12	11	12	23	23	14
5	12	12	12	25	23	17
6	12	11	12	31	28	22

* Packaging: heat-sealed 40 μm orientated polypropylene film
** Washing methods (wash, temperature and time):
1) normal tap water, +6 °C, 1 min
2) normal water containing 100 mg/l active chlorine, +6 °C, 1 min
3) normal tap water, +6 °C, 1 min + normal tap water, +6 °C, 1 min
4) normal water containing 100 mg/l active chlorine, +6 °C, 1 min + normal tap water, +6 °C, 1 min
5) normal tap water, +30 °C, 0.5 min + normal tap water, +6 °C, 1 min
6) normal water containing 100 mg/l active chlorine, +30 °C, 0.5 min + normal tap water, +6 °C, 1 min

On the other hand, washing with plain water or chlorinated water is not effective enough to prevent discolouration of some sliced products, such as sliced potatoes. Traditionally, sulphites have been used for prevention of browning. However, the use of sulphites has some disadvantages. In particular, they can cause dangerous side-effects for asthmatics. For this reason the FDA in the USA partly restricted the use of sulphites in the spring of 1990 (5). At the same time interest in substitution of sulphites is increasing (Anon. 1990a, Anon. 1990b, Langdon 1987, McEvily *et al.* 1991). Studies have been performed at VTT to determine how effectively chemicals and their combinations can prevent discolouration (Ahvenainen *et al.* 1992 and Mattila *et al.* 1993a). Citric acid combined e.g. with ascorbic acid seems to be a promising alternative to sulphites (Table 3).

Table 3. The effects of different chemical solutions (2 l/1 kg potatoes) and of potato variety on the browning index of pre-peeled potatoes (n = 20) during standing for two hours. Washing time was 1 min. Potatoes had been stored for one month before the experiment (Mattila et al. 1993a).*

Chemical	Concentration	pH	Variety/Browning index		
			Bintje	Van Gogh	Nicola
AA	0.1 %	3.1	2	25	44
AA	0.3 %	2.9	1	4	40
AA	0.5 %	2.8	0	17	33
CA	0.1 %	2.7	1	6	14
CA	0.3 %	2.5	2	3	6
CA	0.5 %	2.5	0	2	0
AA + CA	0.1 % + 0.1 %	2.7	0	3	18
AA + CA	0.1 % + 0.3 %	2.6	0	1	11
AA + CA	0.3 % + 0.1 %	2.8	0	2	11
AA + CA	0.3 % + 0.3 %	2.5	0	4	4
AA + CA	0.1 % + 0.5 %	2.5	0	1	4
AA + CA	0.5 % + 0.1 %	2.7	0	3	10
AA + CA	0.3 % + 0.5 %	2.4	0	0	4
AA + CA	0.5 % + 0.3 %	2.5	0	3	6
AA + CA	0.5 % + 0.5 %	2.4	0	1	6
Sodium hydrogen sulphite	0.1 %	4.5	0	1	3
Sodium hydrogen sulphite	0.3 %	4.1	0	0	1
Water		5.7	1	10	67

AA = ascorbic acid, CA = citric acid

* Browning was measured by the so-called browning index, which is based on sensory evaluation using 20 slices cut from the middle of twenty different potatoes and a single trained panelist. This method is used in industrial practice in Finland.

2.4 PEELING

If a vegetable needs peeling as in the case of e.g. potato or carrot, this should be as gentle as possible. The ideal method would be hand-peeling with a sharp knife. If mechanical peeling is used, it should resemble knife-peeling. In Finland, at least one farmer has developed and built a mechanical peeling device which is based on the use of knives. Carborundum, steam peeling or caustic acid disturb the cell walls of vegetables which enhances the possibilities of microbial growth.

The peeling method affects the absorbtion of additives, such as sulphites used for the prevention of discolouration of potatoes. Mokkila and Sorvaniemi (1989) found that when hand-peeled potatoes were treated with 0.7 % $Na_2S_2O_5$-solution, their sulphur dioxide concentration was below 10 mg/kg. When potatoes were peeled with carborundum, their sulphur dioxide concentration was 47 mg/kg on average. Nevertheless, hand-peeled potatoes kept their quality as well as mechanically peeled potatoes. Both browning and sulphite absorption are significantly dependent on the breaking of tissues on the potato surface.

2.5 CUTTING AND SHREDDING

Cutting and shredding should be performed with knives or blades which are as sharp as possible, preferably being made from stainless steel. Slicing with dull knives impairs keeping quality because of the breaking of cells and copious release of tissue fluid. Mats and blades used in slicing can be disinfected with e.g. 1 % hypochlorite solution. A slicing machine must be installed solidly, because vibrating equipment can impair the quality of sliced surfaces.

2.6 PACKAGING AND ITS OPTIMIZATION

In order to obtain a maximal advantage from the procedures described above the prepared vegetables must be packed correctly. On the other hand, even if the best packaging method were used, this would not help unless strict hygiene had been followed and careful washing of the cut product had been performed.

The most suitable packaging method for prepared raw vegetables is modified atmosphere packaging (Kader *et al.* 1989). A modified atmosphere can be created passively by using suitably permeable packaging materials, or actively using a specified gas mixture together with permeable packaging materials. The aim of both methods is to create an optimal gas balance inside the package so that the respiration activity of a product is as low as possible but on the other hand, the oxygen concentration and carbon dioxide levels are not detrimental to the product. In general, the aim is to have a gas composition with 2 - 5 % CO_2, 2 - 5 % O_2 and the remainder nitrogen (Day 1992).

In fact, the achievement of this aim is the most difficult task in manufacturing raw, ready-to-use or ready-to-eat vegetable products of good quality and with a shelf-life of several days. The first problem is that there are no packaging materials permeable enough and suitable for automatic packaging available on the market. One solution is to make microholes of defined sizes in the material in order to avoid anaerobis (Fig. 3).

Another problem is that there is no universal gas mixture suitable for every product, which is very impractical with regard to industrial production. In addition, the most suitable gas mixture or packaging materials cannot be concluded from the respiration activity of a product. For example pre-peeled sliced potatoes must be packed in gas-tight materials, e.g. in nylon-polyethylene-laminate, at low oxygen concentrations (0-1 % O_2+ 20 % CO_2 +79-80 % N_2), whereas grated carrots need highly permeable materials (oxygen permeability 10 000 - 20 000 cm^3/m^2 day 101.3 kPa or microperforated film) and the oxygen concentration should never decrease below 2 %. However, the difference between respiration activities of these produces is very small. The respiration rate at +5 °C is 6 ml CO_2/kg h for sliced potatoes of Bintje variety and 8 ml CO_2/kg h for grated carrot of variety Navarre, as measured by the through-flow system (Table 4).

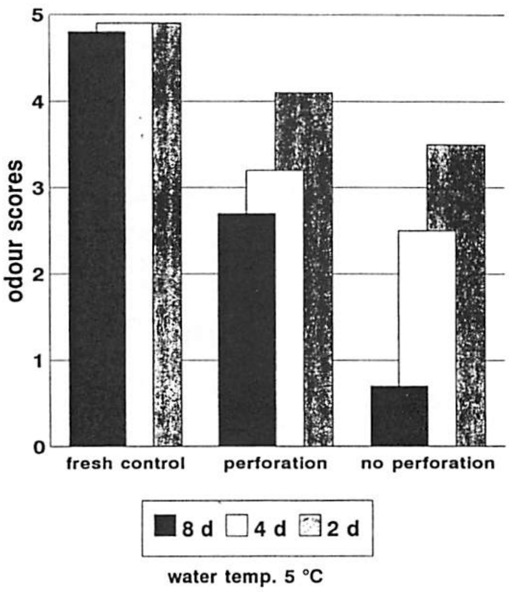

Fig. 3. The effect of film perforation (65 holes/m^2, Ø 350 μm) on the shelf-life (odour) of grated carrot packed in 40 μm PP-O-film and stored at +5 °C. The carrots had been washed in 0.01 % chlorine solution before grating (Hurme et al. 1992).

However, it is possible to obtain a shelf-life of 7 - 8 days for shredded cabbages and grated carrots, if polypropylene-ethylene vinyl acetate-LD-polyethylene film (PP-EVA-LD-PE) or LD-polyethylene film containing ceramic material are used (Fig. 4). The shelf-life of products packed in both these materials is better than in the orientated polypropylene which is generally used in the vegetable industry. The products can be packed in normal air.

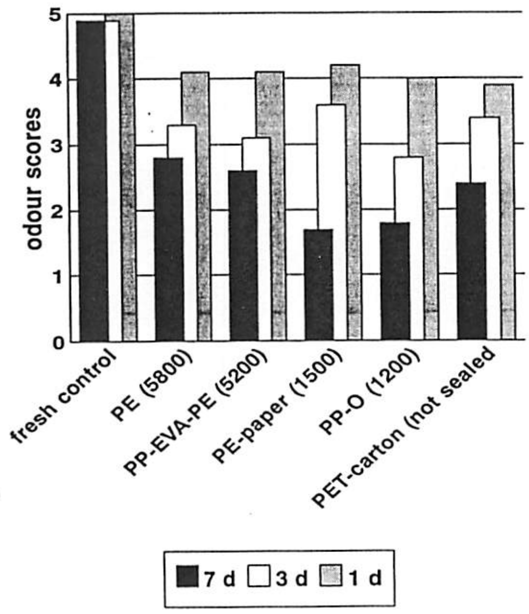

Fig. 4. The effect of packaging material on the shelf-life (odour) of shredded Chinese cabbage stored at +5 °C. The oxygen permeability of the materials is presented in the blocks (cm^3 m^{-2} 24h 101.3 kPa, 23 °C, 0 % RH) (Hurme et al. 1993b).

PE: LD-polyethylene film containing ceramic material,
PP-EVA-PE: polypropylene-ethylene vinyl acetate-LD-polyethylene film,
PE-paper: polypropylene container + PE-LD-coated lid,
PP-0: orientated polypropylene film,
PET-carton: polyester- coated corrugated cardboad box.

Much work has been performed in different laboratories in attempts to model changes in package atmospheres (Kader *et al.* 1989). Most of these attempts recognize the interaction of respiration of the packaged product with the diffusion of respiratory gases through the package. It is obvious that a universal model cannot be created. Even if an exact model of the gas balance inside the package could be created, the shelf life of a minimally processed vegetable would only be 2 or 3 days longer, because suitable means for the prevention of all enzyme activities resulting in off-odour and off-taste of the final product are still unknown.

However, research on this difficult topic must be continued both on a trial and error basis and by attempting to model changes in the package atmosphere.

2.7 STORAGE TEMPERATURE

Regardless of additives or packaging, prepared vegetables must be stored at refrigerated temperatures, at +5 °C or under. In fact, the low temperature is the most critical factor for good shelf life. For example, respiration activity is more affected by temperature than by any other factors (slicing grade etc.) (Table 4).

Furthermore, by keeping the temperature as stable as possible throughout the whole handling and storage process it is possible to reduce the formation of condensation water on the inner surfaces of a package. Condensation water promotes microbial growth and impairs the appearance of packages. In addition, it may alter the gas permeability of the packaging material. Accumulation of condensation water can also be prevented by using packaging materials with surfaces treated with water-repellent material.

Table 4. The effect of temperature, cutting grade and gas composition (air or 5 % CO_2 + 5 % O_2 + 90 % N_2 = MA) on the respiration rate of minimally processed vegetables (Mattila et al. 1993b).

	Temperature (°C)/Gas composition/Respiration rate (ml CO_2/kg h)				
Vegetable/ cutting grade	+2 air	+5 air	+5 MA	+10 air	+23 air
Potato, cv. Bintje					
whole, pre-peeled	3	4	5	9	35
half	4	4	6	12	45
sliced[1]	5	6	8	20	70
Carrot					
whole, pre-peeled	3	5	5	9	30
sliced[1]	6	8	6	17	40
grated[3]	5	10	8	20-25	60-65
Onion					
whole	4	7	5	11	30-33
rings[2]	7	12	9	20	70-73
grated[4]	6	8	6	12	50-55
Leek					
whole leaf	12	15	12	20	65
1/3 leaf + 1/3 stem	16	20	16	30-35	80-90
rings[1]	22	25	20	70	140-160
Chinese cabbage					
half	5	8	5	9	17-20
rough shredding[5]	9	16	11	25	50-55
fine shredding[6]	12	20	14	30	65-70

[1]Thickness of slice or ring 0.2 cm
[2]Cube size 1 cm x 1 cm
[3]Shred size of grated vegetables 0.2 cm
[4]Shred size of grated onion 1 cm x 1 cm
[5]Rough shredding: Chinese cabbage 0.5 cm x 3 cm, white cabbage 1 cm x 3 cm
[6]Fine shredding: Chinese cabbage 0.25 cm x 1.5 cm, white cabbage 0.5 cm x 1.5 cm

3 SELECTION OF CORRECT PROCESSING METHODS

Minimally processed vegetables can be manufactured on the basis of many different working principles (Table 5). If the principle is that the products are prepared today and consumed tomorrow, very simple methods can be used. Most vegetables are suitable for this kind of preparation. The products are suitable for catering, but not for retailing. The greatest advantage of this principle is the low need for investments.

If the products need a shelf-life of several days up to one week, as is the case e.g. with products intended for retailing, then more advanced processing methods as described above are needed. Not all vegetable produces are suitable for this kind of preparation (Table 5).

4 CONCLUSIONS

The key requirements in the minimal processing of raw vegetables are:

* Good quality raw material
* Strict hygiene and good manufacturing practices
* Low temperatures during working and storage
* Gentle peeling
* Careful washing before and after peeling
* Use of suitable chemicals
* Suitable packaging materials and methods

It is important to remember that preservation techniques are not necessarily needed to extend the storage time, but only to ensure the maintenance of good quality within the desired selling time. Furthermore, careful shelf-life studies are necessary before the products can be introduced to the market. For example, when evaluating the sensory quality of prepared vegetables in shelf-life studies, a fresh control sample should be used. Some off-odour and off-flavour may be pleasant but they are not typical for the product.

Much research is needed in order to develop minimally processed vegetable products with high sensory quality and nutritional value. In particular, the products which are intended for retailing need further development.

Table 5. Manufacturing of pre-peeled and/or sliced, grated or shredded vegetables. Working principle/shelf-life (Ahvenainen & Hurme 1993).

Working principle	Demands for processing	Customer	Shelf-life (days)	Examples of suitable vegetables
Preparation today, consumption tomorrow	*Normal kitchen hygiene and tools *No heavy washings, except for potato *Packages may be returnable containers	Catering Restaurants Schools Industry etc.	1-2	carrot cabbages onion rutabega potato iceberg lettuce green lettuce cucumber tomato red beet
Preparation today, a customer uses during 3 - 4 days	*Desinfection *At least washing with water *Permeable packages, except for potato	Catering Restaurants Schools Industry etc.	3-5	carrot cabbages iceberg potato red beet berries
Products are also intended for retailing	*Good desinfication *Chlorine or acid washing *Permeable packages, except for potato *Additives	Retail shops	5-7	carrot Chinese cabbage red cabbage potato red beet fruits berries

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