READY-TO-USE
FRUIT AND VEGETABLES

FLAIR-FLOW EUROPE
TECHNICAL MANUAL
F-FE 376A/00

May 2000

READY-TO-USE

FRUIT AND VEGETABLES

F-FE 376A/00 [May 2000]

This technical manual was prepared for FLAIR-FLOW EUROPE by:

Raija Ahvenainen
VTT Biotechnology
P.O. Box 1500
FIN-02044 VTT
Espoo, Finland

For more information on the FLAIR-FLOW EUROPE dissemination system contact Ronan Gormley at Teagasc, The National Food Centre, Dunsinea, Castleknock, Dublin 15, Ireland.
Telephone: +353-1-8059500; Fax: +353-1-8059550;
E-mail: r.gormley@nfc.teagasc.ie
or visit website **http://www.exp.ie/flair.html**

This technical manual is one of five in the RE-TU-ER (ready-to-use European research) series produced by the FLAIR-FLOW EUROPE dissemination project. This project is funded under the EU FAIR and INNOVATION Programmes (contracts CT-97-3014 and INAMI 0520 respectively).

2000 Teagasc
The National Food Centre
Dunsinea, Castleknock
Dublin 15, Ireland

ISBN 1 84170 106 8

TITLE Ready-to-use Fruit and Vegetables

PREFACE

The acronym 'RE-TU-ER' was coined by the FLAIR-FLOW dissemination team to denote 'ready-to-use European research' and resulted in a series of RE-TU-ER workshops across Europe. The RE-TU-ER workshops are aimed at food SMEs, and especially at the small and very small companies. The goal is to bring results from EU-supported food research projects to food SMEs Europe-wide, in an easily understood form, thereby facilitating application and use of the results both in the short and long term. Each workshop carries a series of handouts and these have been collated into five technical manuals with the following titles:

1. Ready-to-use fruit and vegetables
   [ISBN 1 84170 106 8]

2. Food processing equipment design and cleanability
   [ISBN 1 84170 107 6]

3. Managing the cold chain for quality and safety
   [ISBN 1 84170 108 4]

4. Microbial control in the meat industry
   [ISBN 1 84170 109 2]

5. Freshness, quality and safety in seafoods
   [ISBN 1 84170 110 6]

Ronan Gormley
Project Leader, FLAIR-FLOW EUROPE
Teagasc, The National Food Centre
Dunsinea, Castleknock
Dublin 15, Ireland
Tel: +353-1-8059500
Fax: +353-1-8059550
E-mail: r.gormley@nfc.teagasc.ie

CONTENTS

INTRODUCTION

The consumer demand for high quality foods requiring only minimum amount of effort and time for preparation has led to the introduction of ready-to-use, convenience foods preserved by mild methods (so-called minimal processing methods) only. Minimally processed fruits and vegetables consist of raw fresh cut produce, which have undergone a minimal processing such as peeling, slicing or shredding to make them ready-to-use. Fresh cut vegetables are usually packed in sealed pouches or trays made of polymeric films. Important features regarding quality and safety are:

- the product is raw and the plant tissue remains alive throughout the shelf life,
- the plant tissue may be damaged by the minimal process to various extents,
- the packaging protects the product from microbiological contamination and permits an extension of shelf life,
- fresh cut vegetables are increasingly processed under quality assurance systems,
- HACCP procedures and Good Hygiene Practices are standard items to consider in the production of fresh cut vegetables.

Minimal processing of raw fruits and vegetables has two purposes. First, it is important to keep the produce fresh, but convenient without losing its nutritional quality. Second, the product should have a shelf life sufficient to make distribution feasible within the region of consumption. The microbiological, sensory and nutritional shelf life of minimally processed

vegetables or fruits should be at least 4 - 7 days, but preferably even longer, up to 21 days depending on the market. Because these products are produced without a pasteurisation or equivalent inactivation step, non-spore-forming as well as spore-forming pathogens should be considered as potential hazards. Presence of pathogenic bacteria, viruses, and parasites in the product can be prevented only by Good Agricultural Practices and Good Manufacturing Practices. In order to prevent or control growth of foodborne pathogens in these foods, storage temperature and/or shelf-life are critical factors.

The aim of this manual is to present an integrated approach to modern minimal processing of produce. The present know-how of all the steps of the food chain beginning with raw material, processing and ending with packaging factors affecting the quality, shelf life and safety of minimally processed freshly prepared fruits and vegetables will be introduced.

KEY FACTORS IN THE MINIMAL PROCESSING OF FRESH PRODUCE

Ready-to-use vegetables and fruits can be manufactured on the basis of many different working principles (Table 1). If the principle is that the products are prepared today and they are consumed tomorrow, then very simple processing methods can be used. Most fruits and vegetables are suitable for this kind of preparation. Then, the products are suitable for catering, but not for retailing. The greatest advantage of this principle is the low level of investment. If the products need a shelf life of several days up to one week or even more, as is the case with the products intended for retailing, then more advanced processing methods and treatments using the hurdle concept are needed, as well as correctly chosen raw material which is suitable for minimal processing. Not all produce is suitable for this kind of preparation.

All in all, a characteristic feature in minimal processing is an integrated approach, where raw material, handling, processing, packaging and distribution must be properly considered to make shelf life extension possible. Preservation is based on the synergies of all treatments (Tables 2 and 3).

As examples, processing and packaging guidelines for pre-peeled and sliced potato, pre-peeled and sliced carrot, grated carrot, shredded Chinese cabbage and white cabbage, cut onion and leek are given in Tables 4 - 9, respectively.

Table 1. Requirements for the commercial manufacture of ready-to-use pre-peeled and/or sliced, grated or shredded fruit and vegetables.

Working principle	Demands for processing	Customers	Shelf life (days) at 5°C	Examples of suitable fruit and vegetables
Preparation today, consumption tomorrow	• Standard kitchen hygiene and tools • No heavy washings for peeled and shredded produce; potato is an exception • Packages can be returnable containers	Catering industry Restaurants Schools Industry	1-2	Most fruits and vegetables
Preparation today, the customer uses the product within 3 - 4 days	• Disinfection • Washing of peeled and shredded produce at least with water • Permeable packages; potato is an exception	Catering industry Restaurants Schools Industry	3-5	carrot cabbage iceberg lettuce potato beetroot acid fruits berries
Products are also intended for retailing	• Good disinfection • Chlorine or acid washing for peeled and shredded produce • Permeable packages; potato is an exception • Additives	In addition to the customers listed above, retail shops can also be customers	5-7*	carrot Chinese cabbage red cabbage potato beetroot acid fruits berries

*If longer shelf life up to 14 days is needed, the storage temperature must be 1 - 2°

Table 2. The key factors in the processing of ready-to-use fruits and vegetables.

• Raw material of good quality (correct cultivar/variety, correct cultivation, harvesting and storage conditions)
• Strict hygiene and good manufacturing practices, HACCP
• Low processing temperatures
• Careful cleaning and/or washing before and after peeling
• Washing water of good quality (sensory, microbiology, pH)
• Mild additives in washing for disinfection or browning prevention
• Gentle spin drying after washing
• Gentle peeling
• Gentle cutting/slicing/shredding
• Correct packaging materials and packaging methods
• Correct temperature and humidity during distribution and retailing

Table 3. Hazards, critical control points, preventive and control procedures in processing and packaging of ready-to-use fruits and vegetables.

Critical operational step	**Hazards**	**Critical control point(s)**	**Preventive and control measures**
Growing	Contamination with faecal pathogens Insects and fungal invasions	Cultivation techniques	- use synthetic fertilizer* - Inspect the sources of irrigation water* - use pesticides
Harvesting	Microbial spoilage and insect invasion Cross-contamination	Assesment of produce maturity Handling practices Temperature control Sanitation	- Harvest prior to peak maturity - Minimize mechanical injuries - Harvest in the morning or at night - Employ pickers trained in elementary hygiene
Transporting	Microbial growth Cross-contamination	Time/Temperature Loading Practices Produce Containers	- Keep the temperature low - Avoid long distance transport - Maintain uniform cooling in transport containers - Avoid damage, do not overload the containers - Separate sound and injured produce in the field - Use well washed/disinfected metal or plastic containers
Washing	Contamination from water	Water Washing practices Dewatering	- Use potable water, test routinely for the presence of coliform bacteria - Control microbial contamination by chlorination and antimicrobial dipping - Do not overload the washing tanks/change the water periodically - Remove excess water

* For the produce grown close to ground and consumed raw.

Hazards, Table 3 (Continued)

Critical operational step	Hazards	Critical control point(s)	Preventive and control measures
Sorting	Cross-contamination	Sorter	- Employ sorters who have experience in the inspection of produce
		Lighting	- Provide adequate lighting
		Conveyer	- Clean and disinfect periodically
Packaging	Microbial growth	Packaging film	- Choose the permeability of film correctly - Analyse gas composition routinely by using simple techniques - Use fungicide impregnated film - Dewater the drenched produce carefully - Use films which have antifogging properties
		Relative humidity and temperature control	- Check product/storage temperature at regular intervals
Storage/ Distribution	Growth and spread of micro-organisms	Temperature control	- Maintain the refrigeration of produce in the range of 0-5°C - Prevent moisture condensation by proper temperature control
		Light	- Take the effect of light into consideration*
		Consumer practice	- Provide labelling with instructions for storage conditions

* Light may affect the gas composition in the packaging by inducing photosynthesis in green vegetables.

Table 4. Processing guidelines for pre-peeled and sliced potato.

Processing temperature	4 - 5 °C
Raw material	Suitable variety or raw material lot should be selected using a rapid storage test on prepared produce at room temperature. Attention must be focused on browning susceptibility.
Pre-treatment	Careful washing with good quality water before peeling. Damaged and contaminated parts, as well as spoiled potatoes must be removed.
Peeling	1) One stage peeling: knife machine. 2) Two stage peeling: slight carborundum first, and then knife peeling.
Washing	Washing immediately after peeling. The temperature and amount of washing water should be 4 - 5 °C and 3 liter/kg potato. Washing time 1 min. Obs. The microbiological quality of washing water must be excellent. In washing water, in particular for sliced potato, it is preferable to use citric acid or malic acid with ascorbic acid (max. concentration of both 0.5 %) possibly combined with calcium chloride, sodium benzsoate or 4-hexyl resorcinol to prevent browning.
Slicing	Slicing should be done immediately after washing with sharp knives.
Straining off	Loose water should be strained off in a colander.
Packaging	Packaging immediately after washing in vacuum or in a gas mixture of 20 % CO_2 + 80 % N_2. The headspace volume of a package 2 liter/1 kg potato. Suitable oxygen permeability of packaging materials is 70 cm^3/m^2 24 h 101.3 kPa, 23 °C, RH 0 % (80 µm nylon-polyethylene).
Storage	4 - 5 °C, preferably in the dark.
Other remarks	Good Manufacturing Practices must be followed (hygiene, low temperatures and disinfection).
Shelf-life	The shelf-life of pre-peeled whole potato is 7 - 8 days at 5 °C. Due to browning, sliced potato has very poor stability, the shelf-life is only 3 - 4 days at 5 °C.

Table 5. Processing guidelines for pre-peeled and sliced carrot.

Processing temperature	4 - 5 °C
Raw material	Suitable variety or raw material lot should be selected using a rapid storage test on prepared produce at room temperature. Attention must be focused on respiration activity and whitening of surfaces.
Pre-treatment	Careful washing with good quality water before peeling. Damaged and contaminated parts, as well as spoiled carrots must be removed.
Peeling and slicing	1) One stage peeling: knife machine. 2) Two stage peeling: slight carborundum first, and then knife peeling. Slicing should be done immediately after washing with sharp knives. Optimal size for slices is 5 mm.
Washing	Washing immediately after slicing. The temperature and amount of washing water should be 0 - 5 °C and 3 liter/kg carrot. Washing time 1 min. Obs. The microbiological quality of washing water must be excellent. In washing water, no additives are needed.
Straining off	Loose water should be strained off in a colander.
Packaging	Packaging immediately after washing in air. Suitable oxygen permeability of packaging materials is 2900 cm^3/m^2 24 h 101.3 kPa, 23 °C, RH 0 % (e.g., 50 µm LD polyethylene or corresponding material), but also material with oxygen permeablity about 70 cm^3/m^2 24 h 101.3 kPa, 23 °C, RH 0 % (e.g., 80 µm nylon-polyethylene).
Storage	4 - 5 °C, preferably in the dark.
Other remarks	Good Manufacturing Practices must be followed (hygiene, low temperatures and disinfection).
Shelf-life	Sliced carrot is quite preservable. The shelf-life is at least 7 - 8 days at 5 °C.

Table 6. Processing guidelines for grated carrot.

Processing temperature	0 - 5 °C
Raw material	Suitable variety or raw material lot should be selected using a rapid storage test on prepared produce at room temperature.
Pre-treatment	Carrots must be washed carefully before peeling. Stems, damaged and contaminated parts, as well as spoiled carrots must be removed.
Peeling	Peeling with knife or carborundum machine.
Washing	Immediately after peeling. The temperature and amount of washing water: 0 - 5 °C and 3 liter/1 kg carrot, respectively. The washing time 1 min. Obs. The microbiological quality of washing water must be excellent. It is preferable to use active chlorine 0.01 % or 0.5 % citric acid in washing water.
Grating	The shelf-life of grated carrot is the shorter the finer the shredding grade. The optimum grate degree is 3 - 5 mm.
Centri-fugation	Immediately after grating. Grate may be lightly sprayed with water before centrifugation. The centrifugation rate and time must be selected, so that centrifugation only removes loose water, but does not break vegetable cells.
Packaging	Immediately after centrifugation. Proper packaging gas is normal air, and the headspace volume of a package 2 liter/1 kg grated carrot. Suitable oxygen permeability of packaging materials is between 1200 (e.g., oriented polypropylene) and 5800, preferably 5200 - 5800 (e.g., polyethylene-ethylene vinyl acetate-oriented polypropylene) cm^3/m^2 24 h 101.3 kPa, 23 °C, RH 0 %. Perforation (one microhole/150 cm^3) of packaging material is advantageous. The diameter of the microhole is 0.4 mm.
Storage	0 - 5 °C, preferably in the dark.
Other remarks	Good Manufacturing Practices must be followed (hygiene, low temperatures and disinfection).
Shelf-life	7 - 8 days at 5 °C.

Table 7. Processing guidelines for shredded Chinese cabbage and white cabbage.

Processing temperature	0 - 5 °C
Raw material	Suitable variety or raw material lot should be selected using a rapid storage test on prepared produce at room temperature.
Pre-treatment	Outer contaminated leaves and damaged parts, as well as stem and spoiled cabbage must be removed.
Shredding	The shelf-life of shredded cabbage is the shorter the finer the shredding grade. The optimum shredding degree is about 5 mm.
Washing of shredded cabbage	Immediately after shredding. The temperature and amount of washing water: 0 - 5 °C and 3 liter/1 kg cabbage, respectively. The washing time 1 min. Obs. The microbiological quality of the washing water must be excellent. Washing should be done in two stages: 1) Washing with water containing active chlorine 0.01 % or 0.5 % citric acid. 2) Washing with plain water (rinsing).
Centri-fugation	Immediately after washing. The centrifugation rate and time must be selected so that centrifugation only removes loose water, but does not break vegetable cells.
Packaging	Immediately after centrifugation. Proper packaging gas is normal air, and the headspace volume of a package 2 liter/1 kg cabbage. Suitable oxygen permeability of packaging material is between 1200 (e.g., oriented polypropylene) and 5800, preferably 5200 - 5800 (e.g., polyethylene-ethylene vinyl acetate-oriented polypropylene) cm^3/m^2 24 h 101.3 kPa, 23 °C, RH 0 %. For white cabbage, perforations (one microhole/150 cm^3) can be used. The diameter of the microhole is 0.4 mm.
Storage	0 - 5 °C, preferably in the dark.
Other remarks	Good Manufacturing Practices must be followed (hygiene, low temperatures and disinfection).
Shelf-life	7 days for Chinese cabbage and 3 - 4 days for white cabbage at 5 °C.

Table 8. Processing guidelines for cut onion.

Processing temperature	0 - 5 °C
Raw material	Suitable variety or raw material lot should be selected using a rapid storage test on prepared produce at room temperature.
Pre-treatment	Stems, damaged and contaminated parts, as well as spoiled onions must be removed.
Peeling	Peeling with knife or with pressurized air (dry onions).
Washing	Mild washing immediately after peeling. The temperature of washing water should be 0 - 5 °C. Obs. The microbiological quality of washing water must be excellent. It is preferable to use active chlorine 0.01 % in washing water.
Cutting	The cutting should be done immediately after washing with sharp knives. The shelf-life of cut onion is shorter the smaller the pieces.
Washing and centri-fugation	No washing or centrifugation for cut onion.
Packaging	Immediately after cutting. Proper packaging gas is normal air or gas mixture 5 % O_2 + 5 - 20 % CO_2 + 75 - 90 % N_2, and the headspace volume of a package 2 liter/1 kg onion. Suitable oxygen permeability of packaging materials is between 1200 (e.g., oriented polypropylene) and 2900 (50 µm LD-polyethylene) cm^3/m^2 24 h 101.3 kPa, 23 °C, RH 0 %. If cutting grade is small (i.e., big cuts), quite impermeable materials can also be used, e.g. 80 µm nylon-polyethylene, the permeability of which is 70 cm^3/m^2 24 h 101.3 kPa, 23 °C, RH 0 %.
Storage	0 - 5 °C, preferably in the dark.
Other remarks	Good Manufacturing Practices must be followed (hygiene, low temperatures and disinfection).
Shelf-life	Cut onion has very poor stability, the shelf-life is only 3 days at 5 °C.

Table 9. Processing guidelines for cut leek.

Processing temperature	0 - 5 °C
Raw material	Suitable variety or raw material lot should be selected using a rapid storage test on prepared produce at room temperature.
Pre-treatment	Stems, damaged and contaminated parts, as well as spoiled leeks must be removed. Careful washing with water.
Cutting	The cutting should be done immediately after washing with sharp knives. The shelf-life of cut leek is shorter the smaller the pieces.
Washing	Careful washing immediately after cutting. The temperature of washing water should be 0 - 5 °C and washing time 1 min. Obs. The microbiological quality of washing water must be excellent. It is preferable to use active chlorine 0.01 % in washing water.
Centri-fugation	Careful centrifugation after washing is needed.
Packaging	Immediately after centrifugation. Proper packaging gas is normal air. The headspace volume of a package 2 liter/1 kg leek. Suitable oxygen permeability of packaging materials is between 1200 (e.g., oriented polypropylene) and 2900 (50 µm LD-polyethylene) cm^3/m^2 24 h 101.3 kPa, 23 °C, RH 0 %. If cutting grade is small (i.e., big cuts), quite impermeable materials can also be used, e.g. 80 µm nylon-polyethylene, the permeability of which is 70 cm^3/m^2 24 h 101.3 kPa, 23 °C, RH 0 %. If packaging material is too permeable, the odour of leek can migrate from the package to other products.
Storage	0 - 5 °C, preferably in the dark.
Other remarks	Good Manufacturing Practices must be followed (hygiene, low temperatures and disinfection).
Shelf-life	Cut leek has very poor stability, the shelf-life is only 3 - 4 days at 5 °C.

RAW MATERIAL

The vegetables or fruits intended for pre-peeling and cutting must be easily washable, peelable, and their quality must be first-class. Cold-tolerant pathogens like *Listeria monocytogenes* grow in prepared vegetable salads even though the modified atmosphere packaging (MAP) storage effectively reduces product and microbial spoilage. It is therefore essential to use either a raw material free of contamination, or to clean/decontaminate the produce.

The correct and proper storage of vegetables and careful trimming before processing are vital for the production of ready-to-use vegetables of good quality. The study of various cultivars/varieties of eight different vegetables showed that not all varieties of the specified vegetable can be used for manufacturing ready-to-use vegetables. The correct choice of variety is particularly important for carrot, potato, swede and onion. For example, with carrot and swede, 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 problematic if the variety is wrong. Furthermore, climatic conditions, soil conditions, agricultural practices, e.g., fertilisation and harvesting conditions, can also significantly affect the behaviour of vegetables, particularly that of potatoes, in minimal processing.

PEELING, CUTTING AND SHREDDING

Some vegetables or fruits, such as potatoes, carrots, apples and oranges need peeling. There are several peeling methods available, but on an industrial scale the peeling is normally accomplished mechanically (e.g., rotating carborundum drums), chemically or in high-pressure steam peelers. However, the ideal method is hand-peeling with a sharp knife because peeling should be as gentle as possible. Carborundum-peeled potatoes must be treated with a browning inhibitor, whereas water washing is enough for hand-peeled potatoes. So, if mechanical peeling is used, it should resemble knife-peeling. Carborundum, steam peeling or caustic acid disturb the cell walls of a vegetable which enhances the possibilities of microbial growth and enzymatic changes. Many commercial companies selling vegetable processing equipment have knife-peelers available. In Finland, some potato processing companies peel potatoes successfully in two stages; rough peeling with a carborundum peeler and final peeling with a knife-peeler.

The cutting and shredding must be performed with knives or blades as sharp as possible, these being made from stainless steel. Carrots cut with a razor blade are more acceptable from a microbiological and sensory quality point of view (exudation, cell permeability, weight loss and pH) than carrots cut with commercial slicing machines (a blunt machine blade). It is clear that slicing with dull knives impairs quality retention because of the breaking of cells and the release of tissue fluid to a great extent. With shredded iceberg lettuce, blade sharpness had a small effect but stationary blades increased respiration rate and microbiological counts, and reduced acceptability. Stationary blades probably cause localised bruising near cut surfaces resulting in more spoilage. A chlorine - dip reduced microbial loads and increased accetability scores in both cutting treatments. Undipped rotation cut lettuce scored better than dipped, stationary blade cut lettuce. Thus, a good cutting technolgy is of paramount importance.

Mats and blades used in slicing can be disinfected, for example, with a 1% hypochlorite solution. A slicing machine must be installed solidly, because vibrating equipment may possibly impair the quality of sliced surfaces.

CLEANING, WASHING AND DRYING

Incoming vegetables or fruits, which are covered with soil, mud and sand, should be carefully cleaned before processing. The second washing must usually 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 oxidation during storage. The washing in flowing or air-bubbling waters is more preferable than only dipping into water. The microbiological and sensory quality of the washing water used must be good and its temperature low, preferably below 5°C. The recommended quantity of water to be used is 5 - 10 l/kg of product before peeling/cutting and 3 l/kg after peeling/cutting.

Preservatives, such as chlorine, citric acid or ozone, should be used in the washing water for the reduction of microbial numbers, and to retard enzymatic activity, and thereby improve the shelf life and sensory quality; 100 - 200 mg of chlorine or citric acid/l is effective in the washing water before or after peeling and/or cutting to extend the shelf life. When chlorine is used, vegetable material should be rinsed. Rinsing reduces the chlorine concentration to the level of that in drinking water and also improves the sensory shelf life. The effectiveness of chlorine can be enhanced by using a low pH, high temperature, pure water and correct contact time.

It must be noted that some countries allow raw materials to be washed using chlorine and water baths. In other countries, such decontamination is not approved and washing is with cold water only. In any case, re-contamination of the washed produce by pathogens such as *Listeria monocytogenes* should be avoided, as they grow faster on cleaned produce. Good Manufacturing Procedures should be respected. Raw and cleaned produce should be physically separated.

The alternatives to chlorine are chlorine dioxide, ozone, trisodium phosphate or hydrogen peroxide (H_2O_2). Particularly, the use of H_2O_2 and ozone as an alternative to chlorine for disinfecting fresh-cut fruits and vegetables shows promise.

It is recommended to gently remove the washing water from the product. A centrifugation seems to be the best method. The centrifugation time and rate should be chosen carefully, so that centrifugation only removes loose water, but does not break vegetable cells.

BROWNING INHIBITION

With regard to fruits and vegetables, such as pre-peeled and sliced apple and potato, for which the main quality problem is enzymatic browning causing particularly poor appearance, washing with water is not effective for the prevention of discolouration. Traditionally, sulphites has been used for prevention of browning. However, the use of sulphites have 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. At the same time, interest in substitutes for sulphites is increasing.

Enzymatic browning requires four different components: oxygen, an enzyme (polyphenol oxidase, PPO), copper, and a substrate. In order to prevent browning, at least one component must be removed from the system. In theory, enzymatic browning of vegetables and fruits can be prevented by heat inactivation of the enzyme, exclusion or removal of one or both of the substrates (oxygen and phenols), lowering the pH to 2 or more units below the optimum, by reaction inactivation of the enzyme or by adding compounds that inhibit PPO or prevent melanin formation. Many inhibitors of PPO are known, but only a few have been considered as potential alternatives to sulphites.

It seems that there is no one substance which can alone susbstitute for sulphites in browning inhibition, but combinations of various substances and vacuum or modified atmosphere packaging must be used. All commercially available sulphite-free antibrowning agents are combinations and in addition, most of them are ascorbic acid-based. A typical combination may include a chemical reductant (e.g., ascorbic acid), an acidulant (e.g., citric acid), and a chelating agent (e.g., EDTA). In many cases, the enhanced activity of the combined ingredients is additive, although synergism has also been claimed for several blends of antibrowning agents. In EU-FAIR CT96-1104 - project 'Novel MAP for fresh produce' good results have been obtained by dipping pre-peeled potatoes in ascorbic acid - malic acid solution for 1 - 3 min. The total concentration of the organic acids is 0.75 - 1.00 %. When new methods replacing sulphites are looked for, then it is particularly important to take an integrated approach by choosing proper potato raw material, peeling method, processing and packaging conditions. Furthermore, it is neccessary to examine the effects of these methods on all sensory and nutritional quality attributes, not only on colour.

PACKAGING

The final, but not the least important operation in producing ready-to-use fruits and vegetables is packaging. The most studied and used packaging method for prepared raw fruits and vegetables is modified atmosphere packaging (MAP). Modified atmosphere packaging (MAP) seems a simple enough technology. However, many factors affect the final quality and shelf-life of MAP foods: product respiratory activity, head-space gas, head-space volume to product weight ratio, packaging material, storage temperature, processing, etc. All these factors are inter-related. Respiratory activity depends on storage temperature, processing (cutting, peeling, sharpness of knifes, dipping in chlorine), product (cultivar, physiological age, cultivation and storage histories), oxygen to carbon-dioxide ratio in head-space and the absolute amount of oxygen. The former two have the biggest impact. Vegetables in prepared dishes are "alive" and need oxygen to maintain quality. If oxygen is below a critical limit, they switch to anaerobic respiration. As a result, off-flavours are produced.

The basic principle of MAP is that a modified atmosphere can be created passively by using properly permeable packaging materials, or actively by using a specified gas mixture together with permeable packaging

materials. The aim of both is to create an optimal gas balance inside the package, where the respiration activity of a product is as low as possible and 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 where there is 2 - 5% CO_2, 2 - 5% O_2 and the rest nitrogen.

Actually, to reach this aim is the most difficult task in manufacturing raw ready-to-use or ready-to-eat fruit and vegetable products of good quality and possessing a shelf life of several days. The main problem is that only a few packaging materials on the market are permeable enough to match with the respiration of fruits and vegetables. Most films do not result in optimal O_2 and CO_2 atmospheres, especially when the produce has a high respiration rate. However, one solution is to make microholes of defined sizes and a defined quantity in the material in order to avoid anaerobis. This procedure significantly improves, e.g., the shelf life of grated carrots. Other solutions are to combine ethylene vinyl acetate with orientated polypropylene and low density polyethylene or combine ceramic material with polyethylene. Both composite materials have significantly higher gas permeability than polyethylene or the oriented polypropylene much used in the packaging of salads, even though gas permeablity should be still higher. These materials have good heat-sealing properties, and they are also commercially available. The shelf life of shredded cabbage and grated carrots packed in these materials is 7 - 8 days at 5°C and therefore 2 -3 days longer than in the oriented polypropylene which is generally used in the vegetable industry. The products can be packed in normal air.

Recently, a new breathing film has been patented, which has a 3-layer structure consisting of a two-ply blown coextrusion about 25 mm thick with an outer layer of K-Resin KR10 and an inner metallocene polyethylene layer. It is claimed that this film gives 16 days shelf life at 1 - 2°C for fresh salads washed in chlorine solution.

In another study, grated carrots were packed in OPP (oriented polypropylene), DP, OSM or films with an O_2-permeability of 25K or 200K (µl/m.day) and then stored at 3 and 8°C. Based on microbiology, sensory, exudation, pH and texture, the films with 25 K µlO_2/m.d was most suitable for the storage of grated carrots, while OPP would be second best.

With fresh respiring products, it would be advantageous for the product shelf-life retention to have film permeability increased by temperature at least as much as the respiration rate increases in order to avoid anaerobic conditions. Unfortunately, the permeation rates of most packaging films are only modestly affected by temperature. However, Landec Co. has developed films engineered with an adjustable 'temperature switch' point at which the film's permeation changes rapidly and dramatically. Landec's technology uses long-chain fatty alcohol-based polymeric chains. Under the predetermined temperature-switch point, these chains are in a crystalline state providing a gas barrier. At the specified temperature, the side chains melt to a gas permeable amorphous state. Some commercial packages where Landec's polymers have been utilized are already available.

In another study, a temperature-sensitive film for respiring products has been studied at Brunel University in the UK. The film is made from two dissimilar layers, or from two different thicknesses of the same material,

both layers containing minute cuts. When the temperature rises or falls, the layers expand at different rates. As the temperature rises, the film at the cut edge retracts and curls upwards to give enlarged holes, thus significantly increasing the permeability.

High O_2 MAP treatment has been found to be particularly effective at inhibiting enzymatic browning, preventing anaerobic fermentation reactions, and inhibiting aerobic and anaerobic microbial growth. It is hypothesised that high O_2 levels may cause substrate inhibition of PPO or alternatively, high levels of colourless quinones subsequently formed may cause feedback production of PPO. Carbon monoxide (CO) gas atmosphere was found to inhibit mushroom PPO reversibly. Use of this compound in a modified-atmosphere packaging system would require measures to ensure the safety of packing plant workers.

One interesting modified atmosphere packaging method is moderate vacuum packaging (MVP). In this system, respiring produce is packed in a rigid, airtight container under 40 kPa of atmospheric pressure and stored at refrigerated temperature (4 - 7°C). The initial gas composition is that of normal air (21% O_2, 0.04% CO_2 and 78% N_2) but at a reduced partial gas pressure. The lower O_2 content stabilises the produce quality by slowing down the metabolism of the produce and the growth of spoilage microorganisms. MVP improves the microbial quality at least with red bell pepper, chicory endive, sliced apple, sliced tomato, the sensory quality of apricot and cucumber, and the microbial and sensory quality of mung bean sprouts and a mixture of cut vegetables. Pathogen challenge tests with *Listeria monocytogenes*, *Yersinia enterocolitica*, *Salmonella typhimurium* and *Bacillus cereus* on mung bean sprouts at 7°C have shown that all of the pathogens lost viability quickly during the course of storage.

Maybe the most challenging task is to design a modified atmosphere package for a mixed vegetable salad, where respiration rates of all the components are different. For the salad mixture containing cut carrot, cut cucumber, sliced garlic and whole green pepper a pouch-form package made of 27 µm low density polyethylene film was predicted to achieve a target atmosphere of O_2 3 - 4 % and CO_2 3 - 5 % in the design, and in actual storage tests the package attained an equilibrium gas composition of O_2 2.0-2.1 % and CO_2 5.5-5.7 %, close to the target. The package showed some improved quality retention, such as sensory quality, compared with other designed packages.

When MAP or vacuum packaging is used, there is often a fear about toxin production of non-proteolytic *Clostridium botulinum* or growth of other pathogens, e.g. *Listeria monocytogenes*, particularly when the temperature is over 3 °C. This scenario is often found in the distribution chain. If the shelf-life of vacuum or MA-packed products should be greater than 10 days, and there is a risk that temperature is over 3 °C, then the products should meet one or more of the specific controlling factors detailed below:

1) minimum heat treatment of 90 °C for 10 minutes or equivalent
2) pH of 5 or less throughout the food
3) salt level of 3.5 % (aqueous) throughout the food
4) a_w of 0.97 or less throughout the food
5) any combination of heat and preservative factors which has been shown to prevent growth of toxin production by *C. botulinum.*

Practically, if the aim is to keep minimally processed produce in a fresh-like state, the last mentioned factors (5), and mainly various preservative factors are the only possibilities to increase shelf-life and assure microbiological safety of MA- or vacuum-packed fresh produce.

STORAGE CONDITIONS AND SHELF-LIFE

Ready-to-eat foods have a good safety record, which is partly due to the accepted limits on shelf-life and the, sometimes, stringent national legislation of production and marketing. Storage/display conditions in supermarkets need to be well controlled regarding cooling and handling. Chilling is an important preservative ‘hurdle’. Storage at 10 °C or above is clearly unacceptable because most bacterial foodborne pathogens would grow rapidly on fresh cut vegetables, and even toxin production by *Clostridium botulinum* in some products is possible because of rapid oxygen consumption in the package. Processing, transport, display and intermediate storage should all be at the same low temperature, e.g. 8ºC (or below, preferably 2 - 4 °C) for produce not vulnerable to chilling injury. Changes in temperature should be avoided. Higher temperatures speed up spoilage. Fluctuating temperatures cause-in-pack condensation, which will stimulate spoilage.

An alternative approach is to restrict the shelf-life. This can be relatively short (5-7 days, temperature 5-7 °C), when psychrotrophic pathogens have not enough time to grow and to produce toxin.

FURTHER READING

Ahvenainen, R. Ready-to-use Vegetables - a New Product, a New Challenge. Vortragsband of Flair-Flow workshop 'Der gesundheitliche Wert des Gemusekonsums', 6 May 1996, pp. 47 - 61.

Ahvenainen, R. 1996. New approaches in improving the shelf life of minimally processed fruit and vegetables. *Trends Food Sci. Technol.* **7**(6):179-187.

Baldwin, E.A., Nisperos-Carriedo, M.O. and Baker, R.A. 1995. Use of edible coatings to preserve quality of lightly (and slightly) processed products. *Crit. Rev. Food Sci. Nutr.* **35**: 509-524.

Betts, G. (Ed.). 1996. Code of Practice for the Manufacture of Vacuum and Modified Atmosphere Packaged Chilled Foods with Particular Regard to the Risks of Botulism. Guideline No 11. Campden & Chorleywood Food Research Association, Chipping Campden, 114 pp.

FAIR Concerted Action FAIR CT96-1020. Harmonization of Safety Criteria for Minimally Processed Foods. Rational and Harmonization Report. November 1999, 79 pp.

Gorris, L. 1998. Improvement of the safety and quality of refrigerated ready-to-eat foods using novel mild preservation techniques (AIR1-CT92-0125; 1993-1996)). Review and Transfer Congress European Research towards Safer and Better Foods, Karlsruhe, Germany, 18-20 October 1998, 8 pp.

Gorris, L. 1996. Safety and quality of ready-to-use fruit and vegetables (AIR1-CT92-0125). EU Research Results Ready for Application (RETUER) 21 May 1996, Dublin, Ireland, 12 pp.

Day, B.P.F. 1997. High oxygen modified atmosphere packaging: A novel approach for fresh prepared produce packaging. In: Blakistone, B. (ed.), *Packaging Yearbook 1996*. NFPA National Food Processors Association, pp. 55-65. (EU-FAIR CT96-1104)

Francis, G.A and O'Beirne, D. 1997. Effects of gas atmosphere, antimicrobial dip and temperature on the fate of *Listeria innocua* and *Listeria monocytogenes* on minimally processed lettuce. *Int. J. Food Sci. Technol*. **32**:141-151.

Kader, A.A., Zagory, D. and Kerbel, E.L. 1989. Modified atmosphere packaging of fruits and vegetables *Crit. Rev. Food Sci. Nutr.* **28** (1): 1-30.

Laurila, E., Kervinen, R. and Ahvenainen, R. 1998. The inhibition of enzymatic browning in minimally processed vegetables and fruits. Review article. *Postharvest News and Information*, Vol 9, No. 4, 53N-66N. (EU-FAIR CT96-1104)

Leistner, L. and Gorris, L.G.M. 1995. Food preservation by hurdle technology. *Trends in Food Sci.Technol.* **6**: 41-46.

O'Beirne, D. 1995. Influence of Raw Material and Processing on Quality of Minimally Processed Vegetables. *Progress Highlight* C/95 of EU Contract AIR1-CT92-0125 Improvement of the safety and quality of refrigerated ready-to-eat foods using novel mild preservation techniques, Commission of the European Communities, Brussels, Belgium.

Wiley, R.C. 1994. *Minimally Processed Refrigerated Fruits & Vegetables*, Chapman & Hall.

Acknowledgements

Thanks are due to the EU Commission for its funding of the food R and D projects whose results are given in this manual, and also to the transnational research terms who generated the results. The support of the FLAIR-FLOW EUROPE dissemination project by the EU Commission is also gratefully acknowledged.