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Applications of mild technology to horticultural products: Experiences from the IVTPA*

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Abstract

Mild technologies must satisfy the demand for nutritious, wholesome and tasty foods and, at the same time, must give final products and ingredients some properties useful to improve their utilisation and to increase their economic values. Mild technologies studied and experimented at IVTPA include fresh-cut horticultural products technique (no heat treatment), dehydrofreezing, dewatering-impregnation-soaking (DIS) in concentrated solutions, dehydropasteurisation, active packaging. Attention is drawn to those techniques that are expanding in industrialised countries and are promising in terms of both consumer acceptance and marketing exploitations. This review shows that there is not a unique general method suitable for every raw material and every final product. The choice of the best process depends on fruits and vegetables to be used and on the desired characteristics of the endproduct.

Key words: Mild technology, combined techniques, quality, crops

Introduction

Fruits and vegetables have always been a very important part of the human diet. As there is a well proven relationship between the consumption of fruits and vegetables and good health, there is a notable interest in maintaining the quality level, especially the nutritional content and sensory properties, in both fresh and processed horticultural products. Therefore, the demand for healthy, natural and tasty fruits and vegetables continuously increases and it involves not only the final products to be sold to the consumers but also the ingredients to be included in complex foods or multicomponents products, such as ice creams, bakery, pastry, confectionery, dairy, desserts and prepared meals. Preserved horticultural products to be used as if they are fresh or used as ingredients in the preparation of complex foods, need to undergo some form of treatment or processing to maintain as much and as long as possible not only the sensory characteristics but also the original composition associated with nutritional properties.

It is well known that not all the technological preserving processes are appropriate to reach this objective. Mild technologies and minimal processing are adequate technologies for maintaining a high quality level of horticultural products. The term “mild technology” means the development of preservation techniques that are less severe and therefore less damaging to product quality. The term “minimal processing” means a technique aimed at delivering to the consumer a like-fresh product with an extended shelf-life and at the same time ensuring food safety and maintaining sound nutritional and sensory quality. Since ‘80s IVTPA has been working in the application of minimal processing and mild technologies to fruits and vegetables with the aim of developing novel foods, increasing the shelf life and maintaining the original characteristics of the agricultural products. In addition to satisfying the demand for nutritious, wholesome and tasty foods, mild technologies must also improve the utilisation and increase the economic values of final products and ingredients.

The main ppremise is that quality, safety, storage life and even functional properties depend on the combined effect of several factors (or hurdles), which can have an additive or even synergistic effect[1] and which differ in quality and intensity depending on the particular product (hurdle technology). Hurdle technology is not only applicable to assure food safety, but also to maintain overall quality of foods by using an intelligent combination of hurdles (temperature, water activity, pH, redox potential, preservatives, packaging, competitive microrganisms and others)[2].

A certain set of hurdles, which differ in type and intensity (height of hurdle in Fig. 1A and 1B), is inherent to each product and depends on the characteristics of the product itself. The application of hurdle technology has also been named *combined techniques*. Mild technologies studied and experimented at IVTPA include: fresh-cut horticultural products techniques, dehydro-freezing, dewatering-impregnation-soaking (DIS) in concentrated solutions, dehydro-pasteurisation and active packaging.

Fresh-cut Horticultural Products Techniques

Due to changes in the society, fresh-cut fruits and vegetables have an increasing demand and play an important role in the increase of fresh horticultural food consumption. Usually fresh-cut horticultural foods are considered as convenience products owing to their many advantages: they satisfy the demand for nutritious, wholesome and tasty foods and can be used in many circumstances. Raw material of small size or that have with low commercial value because of their slight external defects can be used for their manufacturing without a loss of quality of the final product. Some years ago a market survey in the USA (data not published) foresaw the spread of fresh-cut horticultural products from catering to home consumption. The same phenomenon is now happening in Europe: in fact, the supermarket chains provide more and more space for these products[3].

Fresh-cut fruit and vegetable products contain live tissues and are freshlike in character and quality. Their quality level depends on aesthetic, nutritional, organoleptic and safety(phytochemicals, nitrates/nitrites, heavy metals and microflora) attributes and is determined by many factors (table 1).

Fresh-cut fruits could be used as a component for fruit salads

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or other food service or consumer products. Fresh-cut fruit salad has another advantage: it could be thought of as a dessert, thus increasing the value of agricultural produce, particularly seasonal fruits. If fresh-cut fruits are to succeed they must be of high quality, with sensory characteristics similar to those of the fresh produce, and have an extended shelf-life[4].However fresh-cut fruit products have not developed commercially as much as fresh-cut vegetables. This is largely due to the susceptibility of cut fruits to enzymatic browning and textural defects which limit product quality and shelf-life.

Fresh-cut horticultural processing (Fig. 2) is a good example of the application of mild technology and the combination of hurdles. In this case no heat treatment is applied and the preservation is achieved by means of hurdles such as temperature (refrigeration), pH control, dipping into antioxidant solutions, washing with chlorinated water and adequate packaging.The hurdle technology can not only help in assuring safety but also in improving quality and maintaining the peculiar characteristics of the horticultural product. Two examples are the utilisation of anti-browning techniques instead of preservatives and the utilisation of active or intelligent packaging. The results of research carried out at IVTPA on anti-browning and anti-softening pre-treatments[5] showed that conventional antioxidants, such as ascorbic and citric acids and their salts, were effective in preventing browning of apple tissues up to 7 days when stored at 2-4°C (tab. 1).

Regarding non-conventional inhibitors of browning, such as L-cysteine, the results reported a good effectiveness at high concentration (5 mM), but fruits pieces immersed in a solution of L-cysteine 5mM might acquire a light scent of sulphur. The threshold of acceptance should be carefully checked by means of sensory analysis. Anti-softening treatments, based on dipping kiwifruit pieces in a solution containing calcium salts, proved to have some effectiveness in maintaining a higher texture of treated fruits when compared to the control samples.

Another hurdle concerns the water activity (a_w). Most fruits and vegetables have an a_w of 0.98 or above and therefore are very sensitive to reduction of a_w as a preservation measure. Reducing a_w to 0.97-0.92 and keeping pH in the range 3.5-4.0 can prolong the shelf-life but decrease the fresh-like character of the product, primarily crispness and turgidity[6]. The limit value of a_w to maintain the fresh-like quality depends on the species and even on the variety under consideration. Therefore the reduction of a_w as a preservation method for fresh-cut horticultural products must be carefully controlled and probably combined with other hurdles, such as pH, if the fresh-like quality has to be maintained. The operations involved in minimal processing (i.e. washing, coring, slicing or cutting) injure the plant tissues and make the horticultural products more perishable than the intact ones. Consequently, sometimes fresh-cut horticultural products should be held at a lower temperature than that recommended for the intact fruits, in order to protect them from quick decay and/or nutrient losses[7]. However, some horticultural products such as bell pepper are highly sensitive to chilling injury.

Examples of the difficulties to establish general methods to process fresh-cut horticultural products, involve green bell pepper and pears. Fresh-cut bell peppers stored at 2°C developed pitting due to chilling injury, while the samples stored at 8°C didn't show marked quality losses[8]. Therefore, the storage temperature of 8°C has been recommended in order to avoid chilling injury in fresh-cut peppers. If the peppers are stored at 8±1 °C, they can have a shelf-life of 7 days. Beyond this time the microbial proliferation is over the limit considered as safe for human consumption[9]. Fresh-cut pears are subjected to rapid enzymatic browning and tissue breakdown. Although considerable data are available on pear polyphenoloxidase (PPO)[10-11] and its substrates[12], there is little information about controlling effectively browning of fresh-cut pears[13] and not much is known about the ideal packaging conditions. Rosen and Kader[14], studying the variety of pear Bartlett, found an increase in carbon dioxide production during storage and also reported the effectiveness of low oxygen concentration in reducing browning and softening. They concluded that citric acid and/or ascorbic acid dips were not effective in controlling browning of fresh-cut pears. However the results of experiments carried out at IVTPA showed that the increase of carbon dioxide concentration inside the packages did not protect by itself the fresh-cut pears from browning. The browning inhibitor treatment (dipping for 15 minutes in a 10g L^{-1} sodium ascorbate solution) was effective in delaying the browning of the fresh-cut pears, especially for the cultivar Abate Fetel. This treatment was chosen not only because it was very simple but also because it gave the highest browning inhibition after several preliminary experiments carried out both *in vitro* and *in vivo* (Pizzocaro F unpublished). *In vitro* experiments were performed on substrate (cathecol), inhibitors (various compounds and mixtures) and partially purified enzyme extracted from pear tissue. *In vivo* experiments were performed with inhibitors (various compounds and mixtures) and diced pears obtained from 4 cultivars (Max Red Bartlett, Decana, Abate Fetel and Kaiser). In conclusion, pears can be processed into fresh-cut products with an expected shelf-life in the range of 8-12 days at 3±1°C; but the highest level of quality is maintained only until 4-8 days of storage[15]. As regards the cultivars examined in this experiment performed at IVTPA, the cultivar Abate Fetel is more suitable for fresh-cut products, while Kaiser cultivar is less adequate. This statement was based on the higher sugar content and on the better acceptance scores obtained by Abate samples in sensory analysis. Mixing various fruits should not be a problem despite different requirements of the individual components.

In fact, the shelf-life of fresh-cut fruit salad (made from apple, clingstone peach and kiwifruit) is 5-7 days if the temperature is kept continuously at 3°C±1°C, which is the same as for the single fresh-cut fruit[16]. The selection of appropriate packaging material and packaging configuration of fresh-cut horticultural products is a difficult task and requires a considerable amount of knowledge[17]. Packaging requirements are influenced by several factors and issues, such as: product quality retention; shelf-life extension; passive and active modification of in-package gas; packaging material selection, including physical and chemical characteristics of potential plastic packaging; package design considerations, i.e. type or style (rigid, semirigid, flexible), size and dimensions; package safety in terms of migration of chemicals from packaging material to food; logistic for transport and distribution. Information for the best quality of finished product is needed on several issues, including: ingredients (for example fruits and vegetables alone or supplemented with other ingredient such as a filling liquid); cultivar(s) to be utilised; ripening stage at harvest; chill injury temperature threshold; sensitivity to C_2H_4 at different levels of O_2 (usually at lower levels than in air) and CO_2 (usually at higher levels than in air); rate of O_2 consumption and CO_2 and C_2H_4 production at the target storage temperature; low O_2 and high CO_2 concentration sensitivity threshold; and mass of product per package. Although some of this information is available from the scientific literature and from packaging material suppliers, much is still unavailable, especially when dealing with mixtures of vegetables or fruits. Therefore specific research should be carried out. At IVTPA some research has been performed on the effectiveness of modified atmosphere packaging and ethylene absorbers placed inside the package. The results of this research are summarised in table 2.

It can be observed that in few cases modified atmosphere or ethylene absorbers showed some effectiveness in extending shelf-life or improving the quality level of final products.

Combined Techniques

The stabilisation processes by combination of hurdles have long been recognised as a safe technique and have proved to be useful in the optimisation of the processing of traditional foods as well as in the development of novel products. There are several well known traditional types of food processing based on direct formulation of foodstuffs by soaking them, whole or in pieces, in highly concentrated solutions: for example candying of fruits, pickling of vegetables, curing or salting of meats, fishes and cheeses. Dehydro-freezing, dewatering-impregnation-soaking (DIS) in concentrated solutions, partial air-drying and dehydro-pasteurisation are the modern versions of these traditional techniques. They are combined techniques based on the hurdle technology and are aimed at obtaining a long-term shelf-life as well as a marked flexibility. This means that different functional properties suitable for various uses can be obtained, thus creating the product diversification. Moreover they allow maintenance of food properties such as texture, colour, aroma and taste. Combined techniques use a sequence of technological steps to achieve controlled changes of the original properties of the raw material[18]. Besides the reduction of water activity, the basic techniques involved include: blanching, refrigeration, freezing and pasteurisation.

As partial dehydration is considered a pre-treatment that allows raw material modifications, these techniques are applied to reach stability (Fig. 3).A reduction of the water activity to achieve a "reduced moisture" ($0.85< a_w <0.95$) or an "intermediate moisture" fruit product ($0.65< a_w <0.85$) (Fig. 4)[19] can be performed by means of several methods, among which we can find air-drying and a combination of air-drying with osmotic dipping.

Dehydrofreezing

Dehydro-freezing is a combination of partial air dehydration and freezing and it can be considered the most appropriate technology to obtain fruit pieces with $a_w >0.85$ suitable for specific applications. Dehydration treatments before freezing are a useful tool to reduce or avoid the negative phenomena that occur in most frozen fruits and vegetables after storage and thawing, caused by the physical and chemical actions of freezing on fruit and vegetable tissues, such as texture losses, structure collapse and juice dripping[20]. Convective air dehydration is usually used for partial water removal and the dehydration is usually carried out up to 50% weight loss, corresponding to 60% water reduction and to 10% relative increase of total solids on the fresh material, equal to a doubling of the dry matter.

Partial dehydration may be still applied to achieve a weight loss of 75-80%, with solid contents in the range 20-50%. Such products may be used for pastry products, where wetting has to be avoided, and are suitable as ingredients for yoghurt, where they adsorb moisture, thus avoiding the separation of whey (fig. 4). In some cases combining air dehydration with osmotic dehydration can be used to obtain better results in the reduction of the a_w above 50% weight loss. In other cases air drying must be replaced by osmotic treatment. For example, the colour of some fruits, such as kiwifruit, can be affected by heat modification, under any form of air drying technique[21], while osmotic treatment has offered excellent results in protecting colour of sliced kiwifruit because it operates at room temperature away from oxygen.

Another example regards the effectiveness of dehydro-freezing in improving the quality of a delicate tissue such as strawberry. The structural collapse after thawing-rehydration of frozen strawberry slices was reduced by adopting partial removal of water by means of air dehydration, osmotic treatments or their combination[22]. A reduction in moisture content of 60%, at least, is needed, irrespective of the dehydration method used, to improve the texture characteristics of thawed-rehydrated strawberries.

Osmotic Dipping, Osmotic Dehydration, Dewatering-Impregnation-Soaking in Concentrated Solutions" (DIS)

Osmotic dipping involves placing the solid food (whole or in pieces) into solutions of high sugar or salt concentration. There is an important outflow of water from the food into the concentrated solution and a simultaneous transfer of solutes from the concentrated solution into the food. So, the impregnation effect is very important. This is confirmed by the fact that the terms "osmotic dipping" and "osmotic dehydration" are being substituted by the term "Dewatering-Impregnation-Soaking in concentrated solutions" (DIS)[23].

The main feature of DIS, compared to other dehydration processes, is the penetration of solutes into the food material which makes it possible to change the food system formulation and make it more suitable to further processing by: adjusting the physico-chemical composition of food by reducing water content or adding water activity lowering agents; incorporating ingredients or additives with antioxidant or other preservative properties into the food; adding solutes of nutritional or sensory interest; providing a larger range of food consistency at the same water activity. The negative aspects are mainly related to: great variability of plant materials (species, cultivar, ripening stage etc.) that make it difficult to define a predictive processing model; lack of adequate response to the management of the osmotic (dewatering) solutions (i.e. reconcentration, microbial contamination, reutilization, discharge of the exhaust solution); difficulty to develop continuous processing equipment. Combining DIS with air-drying offers many advantages, which are in depth described elsewhere[24]. The advantages are the following: the sugar uptake, owing to the protective action of the saccharides, limits or avoids the use of strong antioxidants such as sulphur dioxide; the sensory properties of the end product could be improved because a product sweeter and softer than ordinary dried fruit is obtained; the solid gain increases the total yield in comparison to common drying process; loading of the drier can be increased 2-3 times. Besides texture improvement, as already mentioned above, the penetration of solutes, combined with dehydration effect, can modify the fruit composition and improve pigment, colour, vitamin and aroma retention during both air dehydration and frozen storage. Pigment retention was significantly higher in osmodehydrated strawberry halves than in frozen fruits without a pre-concentration treatment, but no difference was observed among the fruits osmodehydrated in the different sugar syrups[25]. An osmotic step could also improve the stability of ascorbic acid and colour during air drying and frozen storage of osmo-dehydrofrozen apricot cubes by the modification of sugar syrup composition: during air-drying of apricot cubes at 65°C the higher the solid gain, the higher the protective effect on ascorbic acid and the lower the browning. As for vegetable dehydration, incorporating sorbitol into red pepper cubes was effective to reduce colour degradation when they were subjected to air-drying to produce reduced moisture red pepper ingredients[26].

Dehydropasteurisation

Other preservation such as pasteurisation, refrigeration or use of chemical preservatives methods can be applied to osmodehydrated fruits and vegetables to obtain a shelf-life of about 12 months. Pasteurisation is preferred because refrigeration is more expensive while chemical preservatives are being refused by consumers. Pasteurisation is the only intensive thermal treatment; therefore the operating conditions are fundamental in order to maintain a good overall quality of these products. At IVTPA the classical pasteurisation technique has been successfully applied to osmodehydrated cherry, apricot and clingstone peach[27-28]. Time and temperature parameters have been determined to reach the minimum pasteurisation effect (F_p) combined with the protection obtained by of the osmotic treatment (Fig. 5).

As the experiments dealt with reduced moisture fruits, the whole pasteurisation process (heating + cooling) had to give a minimum value of $F_p = 1$ (assumed that T=85°C; z=7°C) because there were other hurdles which avoided an excessive proliferation of microbes. As the classic pasteurisation is based on heating and cooling of the product packaged in a sealed container, the hypothesis was put forward that a further quality improvement might have been achieved by means of an aseptic processing, but the equipment for heating, cooling and packaging pieces of fruits remains to be developed. Therefore an alternative process was set up[29] (Table. 3).

This process consisted of three main steps: 1) direct immersion of osmodehydrated fruit in a sugar syrup, isotonic with the fruit, heated and held at the desired temperature; 2) hot filling in glass jars with the same syrup at the same temperature; this immediately follows the heating step; 3) quick cooling of the sealed jars. Both the classic and the innovative pasteurisation techniques allowed the reduced moisture fruits to be kept at a high quality level up to 12 months; however the direct immersion heating followed by hot filling gave slightly better results only for clingstone peach in comparison with the traditional method.

Active Packaging and Edible Films

Active packaging involves an interaction between the package film or material with the internal gas atmosphere and the food. The objective is to extend the shelf-life of foods while at the same time maintaining quality level and ensuring safety[30]. Active packaging is considered a combined technique because several basic techniques have the potential of being combined in a packaging system to achieve shelf-life extension. These include the following effects and technologies: modified atmosphere packaging; oxygen scavenging from the package atmosphere by means of enzyme or chemical systems; carbon dioxide control by generation, absorption and/or permeation; ethylene control by absorption; controlled release of antimicrobial preservatives onto the surface of the food; controlled release of ethanol into the package atmosphere; controlled release of chemical agents that reduce the loss of shelf-life by non-microbiological means; controlled release of substances that preserve colour; slow adsorption of water from the food surface to lower water activity; temperature control during distribution and transport to the home; time-temperature integrator tags to establish the amount of shelf-life left in a food product or to indicate temperature abuse; light absorbers, especially for UV light to slow oxidation; odour absorber to pull undesirable odours out of the package atmosphere as they are formed; surface treatment of the food to change its properties. The latter is the basic concept leading to edible film. Besides the various traditional processes such as candying of fruits, pickling of vegetables, curing or salting of meats, fishes and cheeses, a so far less used alternative consists of placing an edible protective surface layer (edible film or edible coating) as an additional hurdle for improving overall food quality and stability[31]. Even if edible films and coatings are not meant to totally replace synthetic packaging films, they often reduce the amount of packaging, the need for non edible packaging (for example, allowing conversion from a multilayer, multicomponent plastic package to a single component recyclable package) and they permit new opportunities to prepare novel foods.

By regulating transfer of moisture, oxygen, carbon dioxide, lipid, aroma colour compounds in food systems, edible films and coatings can increase food product shelf-life and improve food quality[32]. Generally, an edible coating is defined as a thin layer of edible material formed on a food; whereas, an edible film is a preformed thin layer of edible material placed on or between food components[33]. In other words, edible coatings are applied in liquid form on foods by dipping, spraying or panning, whereas edible films are pre-formed into solid sheets and then applied on or between food components.

The first edible film made from fruit purees was developed in 1996 and its water vapour and oxygen permeability properties were characterised[34]. Apple-based edible films were excellent oxygen barriers, particularly at low to moderate relative humidity, but were not very good moisture barriers.

Addition of lipids can improve the water barrier properties of fruit based films[32] and a Water Vapour Permeability reduction of 37.5% and 50.2% was obtained by adding, respectively, 160 g kg^{-1} and 270 g kg^{-1} of vegetable oil to an apple puree based edible film. Fresh-cut apple pieces wrapped with lipid added apple edible film maintained their fresh flavour and reduced both browning and moisture loss. A patent application was filed on products and processes for wrapping foods in fruit and/or vegetable based edible films[35].

The high water activity at the surface of fresh-cut apple limited the positive effect of the edible films because the water transfer from fresh-cut apple surface to the edible film resulted in a film swelling after some days of refrigerated storage. Therefore an improvement consisting of wrapping apple pieces which had previously been reduced to a water activity (a_w) close to that of the edible film was considered.

Partial dehydration to 30% and 50% weight loss was performed on apple pieces. Storage temperature, dehydration level and wrapping significantly affected moisture loss from apple pieces during 12 days storage. Temperature had a significant effect on moisture loss from apple pieces which had been dehydrated to 30% and 50% moisture loss. As storage temperature increased from 5°C to 30°C, moisture loss increased significantly. The effect of temperature on 50% dehydrated apple pieces was more apparent than that on 30% dehydrated apple pieces; although at both dehydration levels the effect was significant. Fifty percent dehydrated apple pieces lost significantly less moisture during storage than 30% dehydrated samples. At both storage temperatures and both levels of dehydration, wrapping significantly reduced moisture loss from partially dried apple pieces[36].

Conclusions

There are several tools to develop new products and to introduce them on the market which requires high quality products and ingredients based on fruits and vegetables. After having described the experiences carried out at IVTPA about the application of mild technology, it can be concluded that it is not possible to define a "general" processing method suitable for every material and every product. It is necessary to know which are the characteristics required from the final product and then apply the best process to obtain them. Only by looking into and solving the above-mentioned problems it would be possible to make the most of minimal processing and combined techniques.

If proper care is taken and the needed research done, all the chain from the growers to the table will find some advantages:

* the growers will utilise fruits and vegetable in excess or not completely suitable for the fresh market (size, appearance, minor external defects);

* the industries will produce value added fruits and vegetable products and ingredients with functional properties tailored for specific food systems;

* the consumer will benefit from very high quality and safe foods.

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Table 1. Factors influencing the quality of fresh-cut horticultural products.

RAW MATERIAL ■	PROCESSING ■	STORAGE/DISPLAY/SALE ■
MICROBIAL LOAD■ LEVELS OF CONTAMINANTS■ SUITABILITY OF VARIETIES AND/OR CULTIVARS■ AGRONOMIC CONDITIONS■ RIPENING STAGE■ TECHNOLOGICAL INNOVATIONS- PRE-COOLING AT FARM	COLD STORAGE BEFORE PROCESSING■ STEPS OF PROCESS■ “HURDLES” TECHNOLOGY■ COLD CHAIN■ SPECIFIC PLANTS AND MACHINERY■ CORRECT STORAGE (T, RH ACCORDING TO SPECIES)■ TECHNOLOGICAL INNOVATIONS- PRE-PROCESSING AT FARM (I.E. WASHING)- CONDITIONING OF PLANT ROOMS (T<12°C, AIR FILTRATION, OVER PRESSURE, CLEAN ROOM)- NEW MACHINERY (I.E. WATER OR LASER CUTTING, DRYING OR DRAINING, WASHING)	COLD CHAIN■ PACKAGING MATERIALS AND SYSTEMS■ LABELLING■ TECHNOLOGICAL INNOVATIONS- MODIFIED ATMOSPHERE - INTELLIGENT PACKAGING(PERMEABILITY, ETHILENE OR OXYGEN ABSORBER, TIME-TEMPERATURE INDICATORS, FILLING LIQUID)

Table 2. Browning index of apple pieces dipped in some antioxidant solutions.

ANTIOXIDANT COMPOUNDS	BROWNING INDEX	
	3 DAYS	7 DAYS
Ascorbic acid 16g kg^{-1} + citric acid 10 g kg^{-1}	64.4	-38.1
Sodium ascorbate 10 g kg^{-1} + sodium citrate 2 g kg^{-1}	57.8	28.5
L-Cysteine 5 mM	64.8	25.3
L- Cysteine 10^{-5}M	2.6	-12.0
$CaCl_2$ 2 g kg^{-1} + NaCl 1g kg^{-1}	-28.3	-22.0

Table 3. Synoptic table of the experimental results obtained at IVTPA on fresh-cut processing of horticultural products.

Species	Temperature	Shelf-life of storage	Pre-treatments (days)	Modified atmosphere
Apple (cultivar: Golden Delicious; Granny Smith)	3±1 °C	5-7	Anti-browning	Not necessary
Pear (cultivar: Abate Fetel; Kaiser)	3±1 °C	4-8	Anti-browning	Not necessary
Kiwifruit (cultivar: Hayward)	3±1 °C	4-7	Anti-softening	No advantage
Clingstone peach (cultivar: Carson)	3±1 °C	7	Anti-browning	Not necessary
Apricot (cultivar: Tonda di Costigliole)	3±1 °C	7	Anti-browning	No advantage
Fruit Salad (apple, clingstone peach, kiwifruit)	3±1 °C	7	Anti-browning Anti-softening	Not necessary
Melon (cultivar: Castella)	3±1 °C	11-14	Not necessary	Not necessary
Green bell pepper (cultivar: unknown)	8±1 °C	7	Useless	Not necessary
Fennel (cultivar: unknown)	3±1 °C	4-5	Anti-browning	Some advantage
Bean (borlotto and cannellino types) rehydrated (cultivar: unknown)	3±1 °C	14	Not necessary	Not necessary

Table 4. Time, temperature and F85 parameters of cherry, apricot and clingstone peach pasteurisation.

PASTEURISATION PARAMETERS	CHERRY cv Vittoria (pitted)	APRICOTcv Boccuccia (halves)	CLINGSTONE PEACH cv Fortuna (slices 20 mm thick)
DIRECT IMMERSION			
Heating			
Time (min)	3	6	7
Temperature (°C)	85	85	85
F85	0.11	0.14	0.25
Cooling			
Time (min)	10	10	10
F85	0.89	0.86	0.83
TOTAL F85	1.00	1.00	1.08
TRADITIONAL			
Time (min)	25	23	27
Temperature (°C)	85	85	85
F85	1.00	1.44	1.38

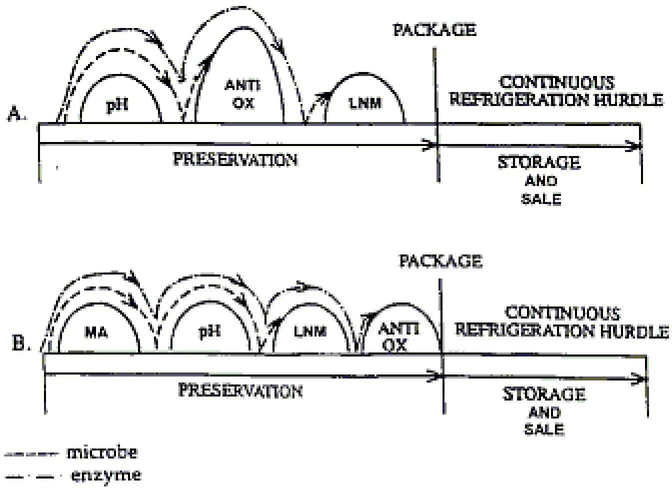

Figure 1. Hurdle technology in fresh-cut horticultural processing (Author elaboration after Wiley, 1994b).

RAW MATERIAL GROWING
⇓
HARVEST
⇓
PRE-COOLING
⇓
RANSPORT
⇓
STORAGE
⇓
SELECTION
⇓
WASHING/BRUISING
⇓
PEELING
⇓
CUTTING
⇓
WASHING
⇓
PRE-TREATMENTS
(ANTIBROWNING / ANTISOFTENING)
⇓
DRAINING/DRYING
⇓
WEIGHING/PACKAGING
⇓
COLD STORAGE/COLD CHAIN
⇓
TRANSSPORT
⇓
DISPLAY/SALE

Figure 2. Flow-sheet of fresh-cut horticultural products processing.

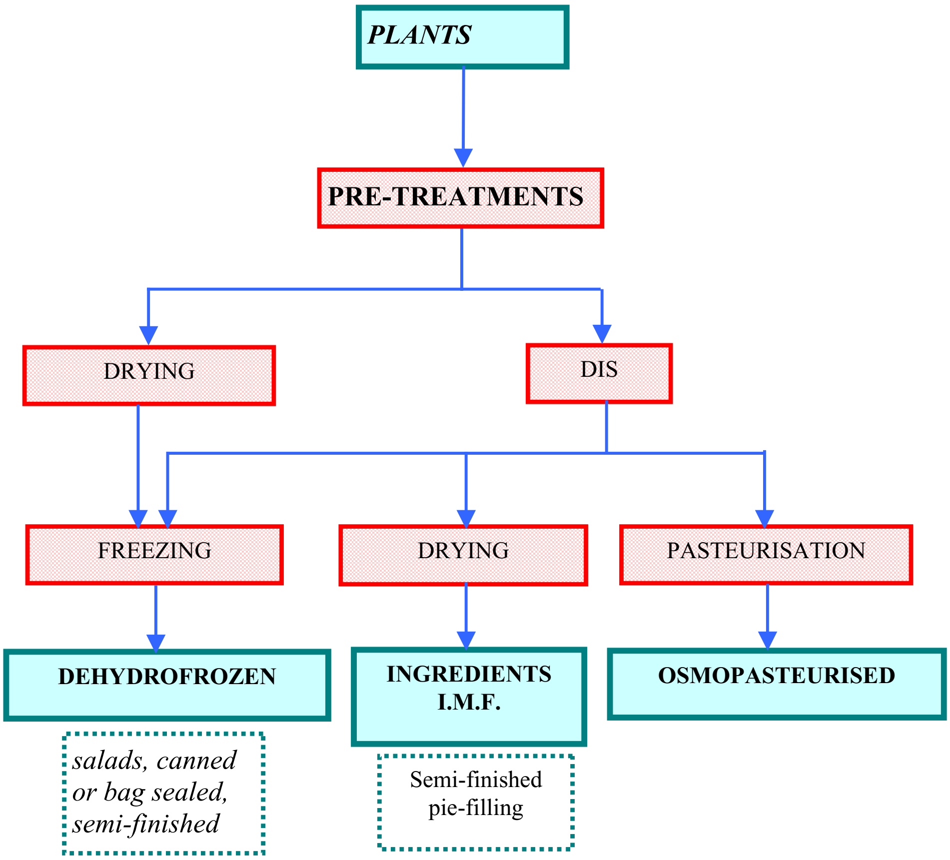

Figure 3. Examples of combined techniques applied to obtain new products based on plant raw material.

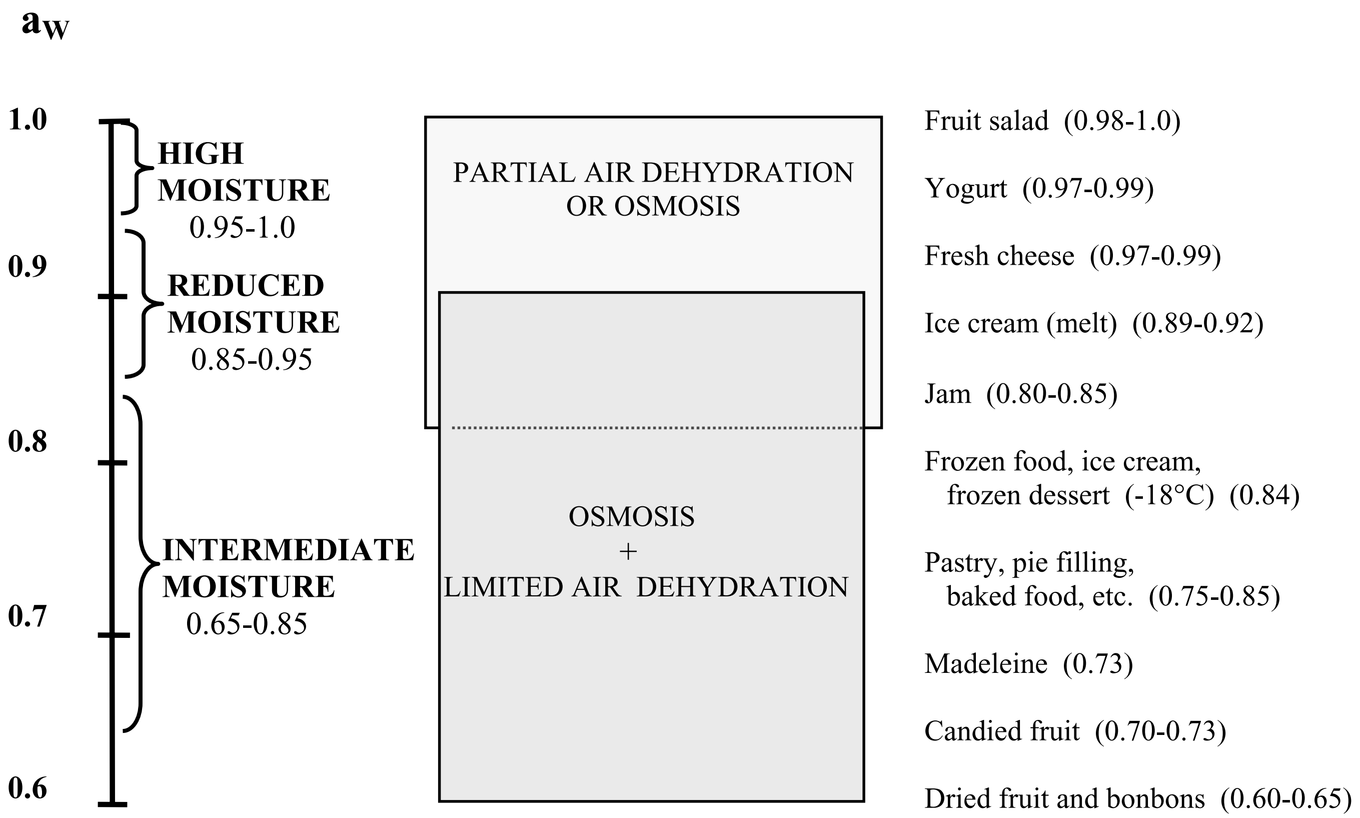

Figure 4. Examples of a_w/process relationship for some fruits ingredients.

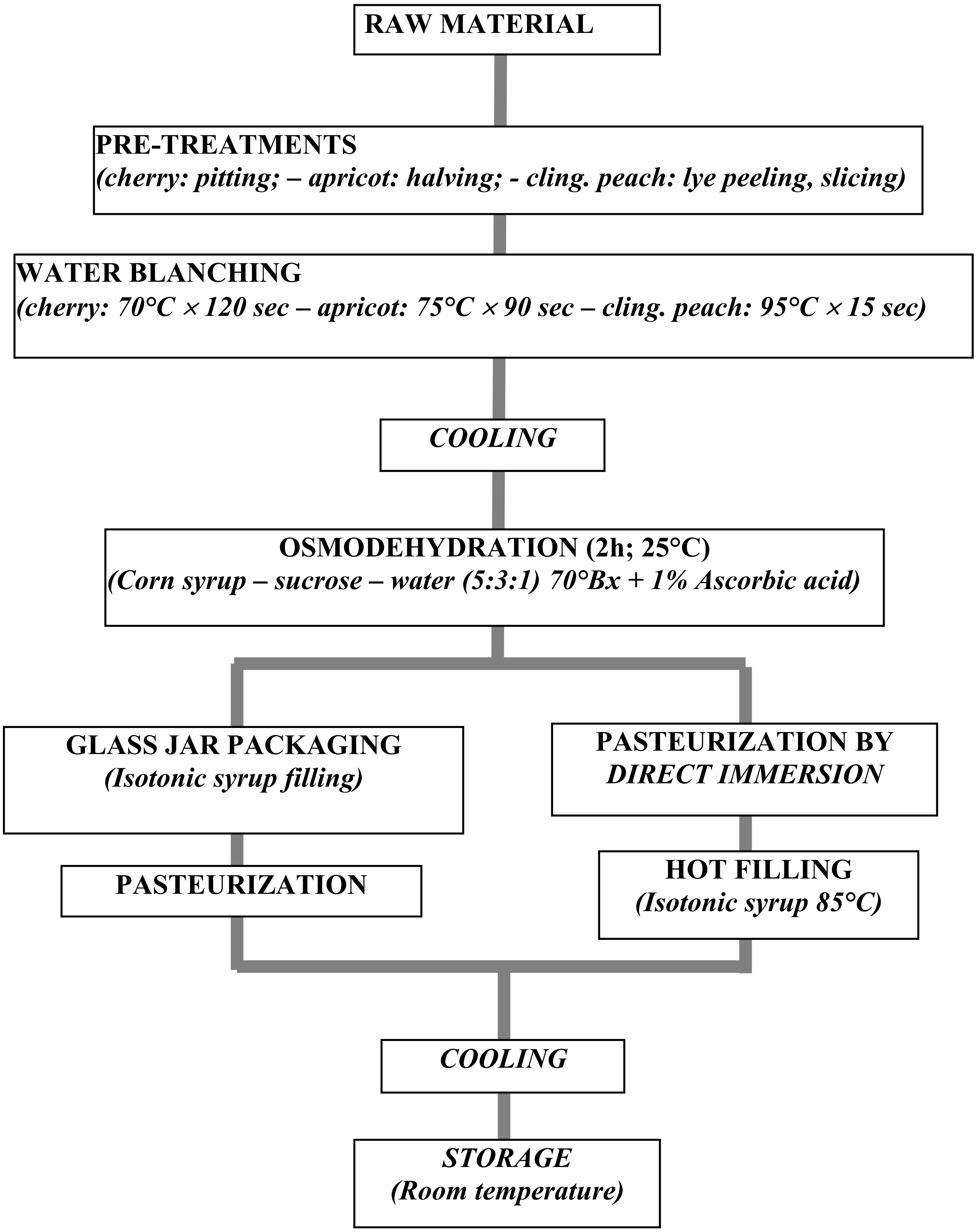

Figure 5. Flow-sheet of classical and direct immersion pasteurization of cherry, apricot and clingstone peach.