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A. HORUBAŁA

ENERGY AND RAW MATERIAL SAVING IN FRUITS AND VEGETABLES PROCESSING

Department of Fermentation and Fruit and Vegetable Technology,
Warsaw Agricultural University

The paper present the progress in research and practical application of energy and material savings in the field of starage of fresh fruit and vegetables, blanching, application of continous method of processing, utilization of HTST method, aseptic packaging, concentration of juices, replacing of metal cans by plastic containers, better utilization of raw materials and byproducts and lowering BOD in discharge water.

Fruits and vegetables intended for immediate consumption or as industrial raw material exhibit a number of characteristic properties:

1. They are highly susceptible to spoilage caused by microbiological, physiological or biochemical factors; in the group of food products spoilage is highest in fruits and vegetables (ca. 25% of the crop).

2. In general, fruits and vegetables have a low energy density — $1.5 \cdot 10^6$ J/kg — about one-tenth of that of cereal and lepulses — $14.7 \cdot 10^6$ J/kg. Very often they are relatively cheap whereas their processing is relatively expensive. In many cases it is cheaper — from both the energy-consumption and financial points of view — to grow fresh fruits and vegetables than to cold-store them or process them for extended storage. This is especially true of developing countries [11].

3. The quality criteria are expressed as amounts of micro-components such as vitamins, mineral substances and, less frequently, as contents of macro-components such as carbohydrates, proteins, or, finally, as energy value. In many cases losses expressed as reduction of fass, sugars, etc. do not reflect the actual losses. It is more realitic to express losses as per cent drop in the content of ascorbic acid, thiamine or, generally, in the content of the more labile components of high nutritive value.

The following conclusions arise from the above observations:

a. The losses of raw fruit and vegetable mass, losses of soluble substances or dry mass during storage and processing are usually lower than the loss of nutritive value.

b. The amount of energy required for processing fruits and vegetables is sometimes very high in comparison to their value. In many developing countries low-temperature storage of fruits and vegetables is economically unjustified and, given the rate of population growth, this method may rapidly become a luxury also in other countries.

The fruit and vegetable technology developed in conditions of relatively inexpensive energy and absence of quality criteria objectively reflecting the nutritional viewpoint. Excessive emphasis was placed on organoleptic quality. The energy crisis of the 1970s prompted an assessment of the existing methods and of individual operations from the energy-consumption viewpoint, as well as analyses of proper utilization of raw materials with more attention paid to nutrition [3, 6].

The effects of these efforts are evident in numerous publications and in new or modified technologies which are less energy-consuming. For the first time in the history of industry, in many of its branches we observe a drop of energy consumption per unit of finished product.

Technological advances in extending shelf life of fresh fruits and vegetables and in their processing are apparent in the following spheres:

— extending storage of fruits and vegetables in controlled atmosphere,

— use of chemical methods in extending shelf life,

— optimization of blanching,

— replacement of both methods with continuous methods,

— use of the HTST method in sterilization,

— use of the aseptic method in packaging fruit and vegetable products,

— use of multiple-effect evaporators and membrane processes in concentration fruit juices,

— use of plastic containers in lieu of can ones in packaging sterile products,

— better utilization of raw materials and by-products.

Recent years have brought many publications on energy consumption in food technology. The data are sometimes divergent as a result of different measurement methods, but certain general tendencies are clear. Exemplary data of this kind are given in Table 1 [1].

The cost of packing materials is relatively high. In terms of energy, the value of a can package always exceeds 100% of the energy value of the packaged product.

As already mentioned, about 25% of the harvested fruits and vegetables undergoes spoilage before reaching the consumer, either during storage or transport or distribution. Significant advances were made in the past years in:

Table 1. Energy consumption in the main technological processes (in MJ/kg)

Natural drying	0.0
Chemical preservation, salting	0.09
Biological preservation	0.20
Cold-storage per month	0.5-2.0
Deep-freeze storage per month	1.1-5.2
Blanching	0.5-1.0
Heat sterilization	1.0-2.4
Radiation pasteurization	0.02
Freezing	1.0-7.5
Concentration by evaporation	0.3-3.5
Cryoconcentration	1.0-2.0
Reverse osmosis	0.1-0.5
Ultrafiltration	0.04-0.2
Industrial drying	3.3-8.1
Metal can per kg	9.0
Glass jar	4.0
Plastic package	3.0-4.8

— cognizing physiological processes in fruits after harvesting,

— chemical methods of preservation involving fumigation, fungicides, immersion in calcium solutions, wax coating, and the use of growth regulators,

— control of environmental factors by adjusting the gas composition of the atmosphere, relative humidity, removing ethylate, ventilation,

— packaging.

The greatest progress is in environment control. Optimum concentrations of CO_2 and O_2, humidity, temperature etc. were determined for most fruits and vegetables. New methods of storage, termed hypobaric and subatmospheric storage, found industrial applications in the past few years.

The control of atmosphere during storage of fruits and vegetables involves:

— storage in controlled atmosphere,

— storage in gas-proof chambers with strictly controlled O_2, CO_2, N_2 concentrations, humidity and temperature,

— storage in modified atmosphere: storage in plastic packages with known parameters of CO_2, O_2, H_2O, C_2H_4 permeability,

— subatmospheric storage with pressure reduced to 100 mm Hg,

— hypobaric storage under reduced pressure of 4-100 mm Hg, temperature ranging from -2 to +15 °C, and air humidity of 80-100% [1, 8].

The hypobaric methods extend the storage time ensured by the universally practiced cold storage by up to ten times. As regards energy consumption, these methods are rather expensive, as a rule requiring temperatures close to freezing.

Promising results in vegetable preservation were obtained at Maryland University in the U.S.A. The researchers there used the gas method to extend the period of storage of fruit and vegetable semiprepared products. Gasses such as CO, SO_2, ethylene oxide inhibit respiratory enzymes thereby inhibiting the development of microorganisms and biochemical transformations in raw products. This method takes up half the energy needed in the production of packed preserves which requires hermetic packages [10].

The period of storing vegetables may be also extended by treating peeled and cut vegetables with certain organic acids which eliminate the possibility of development of some microorganisms and prevent enzyme activity. This method is being investigated at the University of Wisconsin; some experiments have also been performed at authors laboratory.

To sum up, it may be said that so far nothing much had been done to work out simple methods of extending storage periods of fresh fruits and vegetables applicable in all countries.

Blanching is characterized by high heat energy demand, high losses of soluble substances, and heavy pollution of discharge waters with organic compounds. In suitable conditions the loss of water-soluble vitamins during blanching may amount to as little as 5-10%, but very often the figure is 20-50% and in extreme cases even 70%. In some industrial plants blanching and refrigeration account for over 50% of discharge water pollution expressed as BOD.

Recent studies of blanching led to the following results [5]:

— some vegetables till now blanched before freezing may be frozen without blanching provided they are stored at -30 °C for not more than 3-6 months;

— peroxidase activity used as an indicator of proper blanching does not affect the odour of freeze-stored vegetables; in such cases it is enough to supply enough heat to inactivate lipoxygenase, the enzyme responsible for the oxidation of polyunsaturated fatty acids; lipoxygenase is less heat-resistant than peroxidase,

— blanching in HTST conditions gives better results than blanching in classical conditions.

In industry blanching is done with water and steam. A number of new methods have been worked out in recent years, namely:

— blanching of green pea is performed with the fluidization method whereby the peas are suspended in an atmosphere of saturated water vapour and air; the time and temperature of the process may be controlled with precision; the method pollutes discharge water to a very small extent,

— in can blanching: hot water is injected directly into a can filled with peas; the content of the can is mixed and blanched for 20-40 seconds; excess water may be reused together with the ejected peas,

— the pipe blancher is reported to save 40% od steam,

— the thermocyclic blancher (with venturi effect) saves up to 50% od steam,

— the steam blancher with hydrostatic seal uses about 0.77 kg steam per kg of product, i.e. half the amount used in the conventional blancher 0.155 kg steam per kg of product; this type of blancher uses about 50% less energy and 50% less cooling water than the normal blancher.

As we can see, new developments in blanching roughly halved the amount of water needed, creating optimal conditions for the heat process and for losses of nutrients. In some methods energy consumption is over 50% and BOD is over 50% lower than in the classical methods. Despite the satisfying results of many methods there is a continuous need to further optimize the time, temperature and nutrients loss in various vegetable species. This unit operation undergoes speedy changes in recent times.

Another wide field of practical utilization of scientific research is aseptic packaging of fruit and vegetable products. This system of preservation makes use of the principles of HTST. Food products are less heat-damaged, and aseptically packaged fruits and vegetables retain almost all of the nutritive values of raw materials. Economically, aseptic preservation is superiour to conventional preservation or freezing for the following reasons:

— the cost of sterilizing machinery is about 50% lower than the cost of conventional preservation machinery lines, and about 33% lower than the cost of freezing equipment,

— steam consumption is 20-25% lower than in conventional preservation,

— packages may be of lower mechanical strength; they are about 25% cheaper than cans and even less expensive than in the case of plastic packages,

— tanks are stored outdoors which leads to lower building costs,

— transport of products in tanks is cheaper than transport of retail packages,

— lower labour costs during further processing of semifinished products,

— lower consumption of water steam during repacking from large containers to retail packages in aseptic conditions [17].

The thickening concentration of fruit juices is at present the most widespread method in the processing industry. Generally speaking, concentration by water evaporation in vacuum gives satisfactory results in the case of apple juice which is a relatively thermostable product. In the case of berry or citrus fruits juices which are more thermosensitive, the losses of nutrients and the deterioration of organoleptic properties are more pronounced. The aromatic fraction is particularly heat-sensitive.

A better preservation of components is possible using apparatuses or methods involving a minimal period of heating during evaporation followed by sterilization of the aroma condensate by ultrafiltration.

The currently used methods of concentration differ considerably as to energy consumption (Table 2) [12]. As can be seen, membrane processes, mechanical compression and thermocompression are very effective from the energy viewpoint. Membrane thickening moreover gives a good-quality concentrate.

Also worth mentioning are possibilities of improving the economy

Table 2. Energy requirements and costs of various methods of concentration

Concentration method	Requirements per ton of removed water			Cost per ton of removed water	
	total energy MJ	electric energy kWh/t	steam t	total in DM	relative
Evaporation					
Single-effect evaporator	3.475	4	1.10	52.12	1.11
Single-effect evaporator with thermocompression	1.758	4	0.55	26.36	0.56
Single-effect evaporator with mechanical compression	469	46	—	6.90	0.15
Double-effect evaporator	1.778	6	0.55	26.66	0.57
Double-effect evaporator with thermocompression	1.185	6	0.36	17.76	0.38
Double-effect evaporator with mechanical compression	388	38	—	5.70	0.12
Triple-effect evaporator	1.268	8	0.38	19.00	0.41
Triple-effect evaporator with thermocompression	925	8	0.27	13.85	0.30
Triple-effect evaporator with mechanical compression	296	29	—	4.35	0.09
Four-fold-effect evaporator	987	8	0.29	14.78	0.32
Five-fold-effect evaporator	820	10	0.23	12.27	0.26
Six-fold-effect evaporator	745	12	0.20	11.17	0.24
Freezing out					
Single-effect	1.530-2.550	150-250	—	22.50-37.50	0.48-0.83
Four-fold-effect counter-current	1.020	100	—	15.00	
Membrane methods					
Reverse osmosis	102-510	10-50	—	1.50-7.50	0.03-0.17
Ultrafiltration	41-204	4-20	—	0.60-3.00	0.013-0.070

of fruit and vegetable freezing. This may be done by removing the free and loosely associated water from fruits and vegetables (amounting to about 30% of their mass) by drying before freezing. The lower water mass improves the productivity of the freezing line, reduces the mass of frozen fruits and vegetables, and reduces by 25% the costs of labour and the overall cost of freezing [13].

As mentioned previously, packages account for a substantial part of energy required by the production of fruit and vegetable preserves. Package costs sometimes exceed the value of the packaged product. This fact encouraged in the past few years numerous studies of the use of plastic packages instead of metal ones for fruit and vegetable preserves.

The principal advantage of multilayer elastic packages composed mainly of polypropylene, aluminium foil and polyesters lies in energy savings. In general they are cheaper and lighter in transport and processing than metal packages. At present, however, the energy required to produce plastic packages amounts to about 80% of the total energy used in producing canned vegetable [14].

Another problem considered in connection with the economic side of producing packages is the cost of their neutralization, reprocessing or reuse. These issues must be considered together with problems of natural environment protection. Of particular importance here is the cost of neutralizing plastic and aluminium packages. The most advantageous in this respect are reusable glass containers [4, 15].

A better utilization of raw materials may be brought about by minimizing losses of nutritive value during processing and storage, and by minimizing waste products. Large amounts of by-products appear during the production of fruit juices and during rubbing through of fruits and vegetables; they amount to 5-30% of the total raw mass subjected to processing. Losses may be minimized by extraction of water-soluble substances, extraction of substances soluble in organic solvents, the use of apple pomace as dietetic cellulose, extraction of pectic substances, the use of by-products as sources of carbohydrates in alcoholic fermentation, biogass production, drying of apple pomace with biogass energy (biodrying) and many other methods [7, 9, 16].

In practice, as for example in the case of apples, there are numerous efforts to apply technologies without waste products. The utilization of by-products and waste products is sometimes dictated by the need to protect natural environment against pollution.

In conclusion, it may be stated that recent years witnessed significant progress in research and practical applications aimed at:

— substantial increases in the period of storage of fresh fruits and vegetables,

— reducing energy consumption during blanching, preserving and concentration.

One should stress, however, that there are no effective methods of preventing losses of fresh fruits and vegetables during transport, distribution and storage that might be universally applied in all countries.

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Author address: 02-528 Warszawa, Rakowiecka 26/30.

A. Horubała

OSZCZĘDNOŚĆ ENERGII I SUROWCÓW W PRZETWÓRSTWIE OWOCÓW I WARZYW

Katedra Technologii Przemysłu Fermentacyjnego i Owocowo-Warzywnego, SGGW-AR

S t r e s z c z e n i e

Ocena efektywności wykorzystania energii i materiału w przetwórstwie owoców i warzyw jest utrudniona m.in. z powodu:

— różnorodności surowców i kierunków przerobowych,

— różnorodności maszyn, urządzeń, operacji technologicznych i technologii,

— braku obiektywnych kryteriów jakości produktów gotowych z punktu widzenia sensorycznego, odżywczego i zdrowotnego.

Oszczędność energii i surowców uzyskać można przez:
— obniżenie strat energii w procesach technologicznych,
— wykorzystanie technologii bezodpadowej,
— zastępowanie operacji czy procesów bardziej energochłonnych mniej energochłonnymi.

Postęp techniczno-technologiczny w przetwórstwie owoców i warzyw w ostatnich latach dyktowany wymienionymi wymaganiami przejawia się w:
— rozwoju różnorodnych form przechowywania owoców i warzy w regulowanej atmosferze,
— poszukiwaniu chemicznych metod utrwalenia przetworów owocowych i warzywnych,
— stosowaniu ciągłych metod wyjaławiania konserw,
— wykorzystaniu techniki aseptycznego pakowania półproduktów i produktów owocowo-warzywnych,
— wykorzystaniu rachunku optymalizacyjnego w celu maksymalnego zachowania składników odżywczych w konserwach owocowych i warzywnych,
— poszukiwaniu tańszych opakowań w miejsce metalowych i szklanych,
— stosowaniu aparatów wypornych wielodziałowych z wykorzystaniem termokompresji i kompresji mechanicznej,
— stosowaniu procesów membranowych w zagęszczaniu soków owocowych,
— wykorzystaniu elektronicznych systemów kontroli dawkowania ciepła,
— obniżeniu strat suchej masy w procesie blanszowania,
— łączeniu metod suszenia i zamrażania,
— wykorzystaniu w transporcie półproduktów i produktów opakowań zwrotnych i zbiorczych,
— łączenia metody wyciskania i ekstrakcji w procesie otrzymywania soków,
— stosowaniu technologii bezodpadowych,
— wykorzystaniu produktów ubocznych czy odpadowych na cele spożywcze.

Średnie zużycie energii w różnych procesach technologicznych przetwarzania i utrwalania żywności przedstawia tabela 1 zaś porównawcze zużycie energii w różnych metodach zagęszczania soków owocowych — tabela 2.