Role of Agricultural Engineering in Post-harvest Technology for Fruits and Vegetables in Japan

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The dietary pattern in Japan has been changing to western-style year after year. The tendency can be seen in the sharply decreased consumption of rice, the staple food, and the increased consumption of western-style foods such as bread, noodles, meat, etc. In addition, the consumer also has a trend to prefer western-style vegetables such as lettuce, tomatoes, green peppers which are relatively new crops and much more perishable than traditional vegetables. On the other hand, the producing areas of fruits and vegetables have become farther from consuming areas which have a large number of populations.

These overall changes in the producing and consuming patterns have led to the development of a new technology how to transport fruits and vegetables without damaging their qualities, for instance. One of distinguished techniques can be seen in precooling and packinghouse facilities.

In this paper, some current situations of post-harvest handling technology for fruits and vegetables (precooling and packinghouse facilities) and the important role of agricultural engineering in that fields will be described.

Precooloing facilities

The first large-scale trial of precooling in Japan was made with vacuum cooling of lettuce in 1969 by the support of Agency of Science and Technology. Thereafter, a large number of commercial scale facilities were installed, especially in Nagano Prefecture. Nagano is located in the central high land in Honshu at the elevation of about 1000 m and can produce a large quantity of vegetables in the summer season by taking advantage of cool climate.

Methods of precooling presently used in Japan are air cooling, vacuum cooling and hydro-cooling. Most of these precooling facilities are subsidized by the Ministry of Agriculture, Forestry and Fisheries and operated by agricultural cooperatives (Nokyo).

1) Hydro-cooling

As compared to other types, this method is useful for fruits and vegetables having low surface to volume ratios, but it has a risk of microbial contamination of cooling water and a problem of residual water on the products.[1] In Japan, there is a serious restriction in adding antiseptic chemicals to cooling water. Therefore, only one facility of this type is used for precooling of sweet corn commercially in Hokkaido without the chemical. In this case, the products in a 20 kg-capacity plastic box are soaked in cold water of 1 to 2°C for about half an hour. After cooling, the products are transfered to cold storage room to stay overnight so that uniform temperature may be obtained and residual water may also be removed. The 10 kg-capacity corrugated fiberboard box is usually used for shipment. An oxygen absorbent is sometimes applied in the box to keep the freshness.

2) Air cooling

Air cooling is the most popular precooling method in Japan. The early type of air cooling

facility consisted of room cooling which took many hours to cool the products deeply. Newly designed air cooling facilities consist of forced air cooling in order to shorten the cooling time. However, there still remain problems to be solved as to the position, size and arrangement of vent holes for container, stacking pattern, and handling of load.

3) Vacuum cooling

The major parts of this facility consist of vacuum chambers, vacuum pump, cold traps and refrigerator. At present, in many cases, two vacuum chambers are installed to be used alternately for easy handling of the load. Depending on the kind of commodity, time required for reducing the product temperature by 30°C is usually 20 to 40 min under the evacuated condition of 5 to 6 mm Hg. Though the capacity of the chamber depends on the scale of producing area, most of the facilities can treat the products of 4000 to 6000 kg at a time on the average.

The products precooled by this method are lettuce, sweet corn, cabbage, spinach, etc. Vacuum cooling is well known as the fastest precooling method for leafy vegetables; however, increased respiration rate and leaf yellowing after treatment under highly exhausting speed are reported.[6]

In addition to these technical problems, there also is an economical problem because the intial cost of this facility is very expensive, and the operating period is less than half a year even at the maximum. From this point of view, a movable type of vacuum cooling facility has been developing so that it can be used after harveast for other purposes such as drying of rice and wheat, curing of satsuma mandarins, and low pressure storage.

Packinghouse facilities

During the past two decades, the population of rural districts in Japan has decreased consistently, which has created a serious problem of labor shortage. On the other hand, the scale of production per unit agricultural cooperative has been growing up because concentrated production of regionally specialized commodities has increased very much.

In response to these problems, it is necessary to construct a large number of packinghouses of automatic type in producing areas. The packinghouse facility in Japan started initially for satsuma mandarin. At present, various types of packinghouse facilities for all kinds of products have been installed.

In many cases, the facility consists of not only a packaging line, but also an automatic sorting line for the size or the weight of the products. These facilities are constructed in conjunction with other facilities; for instance, precooling, degreening, storage, etc. Moreover, the products are graded into several classes by the external appearance and then the decayed or rotten products are removed from the lines. These operations are usually done manually, which causes a bottleneck and reduces the efficiency in the packinghouse lines. In case of satsuma mandarins; for instance, the appropriate capability to grade the fruits by hand is less than about 800 kg per hr.

For the purpose of manufacturing an automatic grading machine that has a capability to detect the external appearance at a high speed, several papers have been reported on nondestructive techniques.[2] Up to today, they were only laboratory-scale experiments; however, a newly designed facility will become available commercially in the near future.

Several types of damages that occur in packinghouse lines often cause serious problems. Rough handling like dropping and vibrating practices causes not only a mechanical injury, but also a physiological deterioration.[3] From this viewpoint, an electrical sizing machine appears to be successful. This machine has already been used for satsuma mandarins, apples, pears, watermelons, and persimmons with a successful reduction of injury.

Recent research of agricultural engineering related to post-harvest handling of fruits and vegetables

Table 1 shows the number of papers that have been reported in the field of post-harvest handling technology during the past 15 years. Number of reports on the subjects of washing, sorting, transportation and packaging are relatively fewer than that of other fields since the researches on these subjects have recently started and there have been few research engineers in spite of necessity of engineering approach.

On the basis of the concept of unit operation, post-harvest handling technique of fruits and vegetables is thought to be a combination of several units such as precooling, grading, packaging, storage, transportation, etc. Supposing that the role of agricultural engineering in these fields is to find the way to systematize or optimize the handling conditions, physicomechanical properties of the products are one of the most important aspects to be studied in order to obtain such a successful result as in other engineering fields.

It is desirable that the research on physicomechanical properties becomes a fairly favorite field for agricultural engineers in Japan. The subjects of this research may include the following aspects:

1. Fundamental physical properties
   Volume, Surface area, Weight, Shape, Specific gravity, etc.
2. Mechanical properties
   Rheological behavior under static, quasi-static and dynamic stress, Modulus of elasticity, Acoustic property, etc.
3. Optical properties
   Reflectance and transmittance properties related to color detection, Delayed light emission, X-ray, Fluorescence, Infrared, etc.
4. Electrical properties
   Dielectric property and electrical capacity.
5. Mass and heat transfer properties
   Thermal conductivity, Specific heat, Gas permeability, Mass and heat diffusion coefficient, etc.
6. Fluiddynamic properties
   Pressure drop, Viscosity, Terminal velocity, etc.

From an engineering point of view, it is rather important to use these properties for the design or development of practical facilities and handling techniques than to find measuring techniques. To emphasize the importance of physicomechanical properties of products, the following two examples will be demonstrated with potatoes and satsuma mandarins.

Table 1. Number of reports published in the field of post-harvest technology for fruits and vegetables during the past fifteen years

Item	Name of journal				
	JSAM	JSHS	JSFST	JAF	Total
Quality detection	15	3	29	0	47
Washing	0	0	1	3	4
Sorting	11	1	0	5	17
Storage	8	47	26	4	85
Packaging	4	3	1	0	8
Transportation	12	4	0	0	16
Standardization	0	0	2	0	2
Others	21	17	25	0	63

JSAM: Journal of the Society of Agricultural Machinery, Japan.
JSHS: Journal of the Japanese Society for Horticultural Science.
JSFST: Journal of the Japanese Society of Food Science and Technology.
JAF: Journal of the Society of Agricultural Structures, Japan.

Shihoro Nokyo, which is the biggest producing cooperative of potatoes in Japan, has urgent problems that need to be worked out from the viewpoint of agricultural engineering such as:

1) Reduction of mechanical injury of potatoes during handling practices

Abrasion and browning tissue are typical bruises of potatoes. The former allows initiation of decay during storage or shipment, and the latter lowers not only the marketability for fresh use but also processibility.

Since mechanical property of potatoes subjected to dynamic stress is especially necessary to estimate the safety of products during handling, several types of dropping tests have been reported.[5] In many cases, the Hertz's impact theory of elastic sphere has been used to determine an acceptable stress of potatoes without bruise; however, a finite element model method is used to analyze the distribution of stress under the loading surface in the latest report. Furthermore, in order to estimate an in-transit injury, the theory of fatigue has been used and the technique of simulated transportation has been developed progressively.[4]

2) The suitable capacity or height of bulk handling

Potatoes are subjected to static stress for a long period of bulk storage. In this case, it is necessary to get an information of mechanical property of potatoes because that situation causes a creep phenomenon and permanently deformed potatoes. To study on the creep phenomenon under the static load, a linear rheological theory about four elements model or multi-combined Voigt model has been generally used; however, a present tendency shows an expansion to a nonlinear viscoelastic theory.

3) The design of air circulation system of storage room

It is well known that low doses of irradiation of Co^{60} is effective in preventing potatoes from sprouting. By this irradiation practice, the storage period could be extended to about seven months after harvest; however, the increment of decayed potatoes during storage became a new problem because it was difficult to circulate the air inside a 1500 kg-capacity bulk container in which the potatoes are filled in bulk.

Storage room having a forced air circulation system is going ahead after laboratory scale tests. This problem includes a simultaneous transfer of heat and mass between air and potatoes, and then computer simulation method is mighty means in order to analyze the problem. On the other hand, evapotranspirative characteristics of potatoes related to temperature, humidity and air velocity have to be made clear as well as aerodynamic property such as a pressure drop of potatoes in the container.

Secondly packinghouses of satsuma mandarins have several problems to be solved urgently by agricultural engineering research. For instance:

1) Improvement of drying or removing residual water on the peel after washing practice.

Early ripening satsuma mandarins, especially produced in southwestern producing districts are usually washed and waxed before shipment. Washing practice is important to remove chemical substance on the peel; however, residual water often causes a big trouble because evaporated water raises humidity in carton box and not only induces deterioration of the fruit, but also weakens the strength of the carton box. This problem is also of the category of a simultaneous transfer of heat and mass; however, a definitive mathematical model which can explain the evaporating phenomena of water during drying process has not been found yet.

2) Reduction of mechanical injury on the lines

Inside the packinghouse lines, the fruit is subjected to a serious mechanical injury. According to a recent investigation of packinghouse lines, the repetition of dropping

practice and the totalized dropping height, which depend on the type of lines, reach 15 to 30 times and 4.6 to 6.3 m, respectively.

It is important that physiological deterioration such as increment of respiration rate, accumulation of ethanol, oxygenation of ascorbic acid and decrease in acidity are induced by the mechanical injury. Late ripening fruits are more affected than early ripening ones. Restrictive height and number of drops have to be basically determined with respect to mechanical property of the fruit.

3) Nondestructive technique to detect the external appearance (color, defect) and internal quality

To find a technique applicable to automatic grading machine, researches on nondestructive methods have been made actively during the past five years.

One of them is concerned with the detection of external and/or internal color and the defect on the peel by means of reflectance, transmittance and delayed light emission. The practical sorting machine with TV scanning method has already been manufactured; however, there still remains a few problems with respect to low efficiency.

In recent years, we have seen very rapid advances in the post-harvest technology of fruits and vegetables in Japan. This technology which aims at minimizing losses of products may become more important from a point of saving energy and resources.

It is sure that this technology will develop with contributions of not only agricultural engineering but also other fields as plant physiology, food science, etc.

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