much concerning the triggering of the numerous ripening processes. If ethylene is the hormone which initiates all these reactions, what materials are present in the fruit tissue which delay the effects of ethylene until the proper time in the fruit's ontogeny? Are these materials synthesized *in situ*, or are they translocated from adjacent leaves? At what locus is the ethylene stimulus received? It is obvious that the area of post-harvest physiology will be a fertile field for research for many years to come.

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ENVIRONMENTAL FACTORS AFFECTING RIPENING OF FRUITS

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Since the scope of this subject is too vast to cover details, only a broad outline pointing out some unanswered questions will be given.

Preharvest factors

We usually think only of environmental factors in the storage when we consider factors affecting ripening. Yet the pattern of ripening may be affected by orchard environment. Storage disorders which in turn may affect the course of ripening may also be influenced by orchard environmental factors.

Climate

Quality factors and susceptibility to storage disorders of the apple have been shown to be affected by climate (22). A compendium of abstracts covering the effects of weather on the keeping quality of fruits has been published (1). In spite of all of this work, it can be concluded that we don't know very much about the effects of climate on subsequent ripening rates. Only when we grow bearing trees in phytotrons can we begin to understand the effects of the climatic complex on ripening.

Culture

It seems generally agreed that high levels of nitrogen fertilization may result in higher than normal post harvest respiration of fruits like the apple (26). While the effects of other elements such as K and P have been studied as they affect quality, little is known about their effects on ripening. There is some suggestive evidence that P may counteract some of the effects of high N on the keeping quality of apples (29).

It is often observed that fruits from young trees do not keep as well as those from older trees. Is this because of fruit size, nitrogen level, or other factors? Crop size and hence fruit size is known to affect keeping quality, and yet studies on the effect of fruit size on respiration rate are confusing (26).

Stop drop chemicals such as 2,4,5-TP used on apples have been shown to accererate the ripening rate of apples (25). There is both the indirect effect of picking the fruits later and the direct effect of these materials in stimulating respiration and ripening. The effect of growth reducing chemicals such as N-dimethylaminosuccinamic acid as they affect ripening will be covered in another paper in this symposium.

Studies have been made on the effect of pesticides as they affect the respiration rate of apples (19). Claims that a particular pesticide causes apples to ripen more slowly seem generally unjustified. Studies on pesticides should include their effect on fruit keeping quality. This is seldom done.

Harvest

The extent to which certain fruits are pre-climacteric or post-climacteric at the time of harvest influences subsequent ripening patterns. Hence, time of harvest is an important factor affecting ripening.

The mere act of picking may influence the ripening rate of certain fruits. Detachment accelerates the ripening of fruits like the avocado (3) and apple (8 and 18). It has been postulated that an inhibitory auxin was contributed by the leaves while the fruit is attached to the tree (4 and 18). If we could find out what this material is, perhaps we could exploit it.

With fruits such as citrus, apples, bananas, and avocados, bruising often stimulates ripening. These findings certainly argue for careful handling of fruits at the time of harvest.

Pre-storage treatments

Waxing of citrus is a long established practice. The wax cuts transpiration losses but it is used primarily for appearance. It is sometimes a carrier for fungicides with citrus and a carrier for diphenylamine for scald control with apples. Waxing can reduce the ripening rate of fruits. If the least bit too much wax is used, there can be anaerobic respiration, however. Waxing of apples is currently experiencing a resurge of interest in Washington. (21).

The use of polyethylene box liners has little effect on ripening of pears and apples unless the liners are sealed. The danger of excessive carbon dioxide accumulations in sealed liners can be avoided by using calcium hydroxide inserts. There is still the hazard of dangerously low oxygen levels in sealed liners. (24).

Radiation treatments have been proclaimed as a means of lengthening the storage life of fruits. They do present the possibility of pasteurization for fungus control (15). There are enough undesirable side effects, however, to throw doubts on the use of this procedure to reduce ripening rates (14 and 15). Good refrigerated storage is possibly even more important with irradiated fruits than with non-irradiated fruits.

Storage factors

Temperature

The use of reduced temperatures to inhibit ripening has been known since time immemorial. A temperature coefficient or Q_{10} of 2-3 holds surprisingly well for apples. Recently, it was shown in the range of 38-45°F that the Q_{10} was 2 for carbon dioxide and 3 for oxygen with apples (7). Yet the ripening of pears as influenced by temperature does not follow this pattern. For example, it has been shown that the storage life of Bartlett and Anjou is 35% longer at 33.8°F than at 32°F (19). The temperature coefficient of 2-3 does not hold for fruits at high temperatures such as 90-95°F (6). That is, ripening is not as rapid as one might expect at high temperatures.

It has been well demonstrated that a period of low temperature storage is required with certain varieties of pears to attain normal ripening (9). Why is this true? Does chilling lower the threshold for ethylene stimulation or is something else involved?

Some fruits and vegetables will not ripen normally at low but non-freezing temperatures. For example, Valery bananas cannot be stored at temperatures below 57°F. At lower temperatures they develop chilling injury and fail to ripen normally. Some of our apple storage disorders such as brown core and soft scald could be classified as chilling damage. One of the real break-throughs we need is an explanation of the nature and control of chilling injury. It is true that very high relative humidities and low oxygen atmospheres minimize chilling of bananas (2) but these findings have not solved the chilling problem. What is the basic nature of chilling injury? It may be true that oxalacetic acid accumulates in apples before a type of chilling damage occurs (12), but can this be offered as an explanation of chilling damage?

Carbon dioxide

It is well known that elevated levels of carbon dioxide will inhibit ripening. We are limited by the amount we can use on a given variety by its sensitivity to this gas. Why can strawberries tolerate 30% carbon dioxide for a week or more and yet citrus can tolerate practically none? It has been found that succinic acid accumulation accompanies carbon dioxide injury in apples (11). Was this accumulation merely concomitant with the injury?

Oxygen

Reduced oxygen levels will inhibit the ripening of fruits and vegetables. The use of elevated carbon dioxide and reduced oxygen levels in refrigerated storage is called controlled atmosphere (CA) storage (21). The level of oxygen that one can use without anaerobiosis is governed by the variety and temperature (6). Susceptibility to low oxygen injury even varies from orchard to orchard and from year to year. The effects of carbon dioxide and oxygen are additive in respiratory response but not as regards lengthening the storage life (6). This finding illustrates the point that we sometimes tend to over-emphasize respiration per se as it relates to the total ripening picture.

Volatiles

It is well known that ethylene and acetylene can stimulate the ripening of pre-climacteric fruits. Ethylene may be supplied artificially as in a banana ripening room. It may be supplied from endogenous ethylene from the fruit. Or it may come from fungi such as Penecillium digitatum in a lemon storage room.

It seems well agreed now that the effect of ethylene or ripening is not important below 45-50°F (26). Yet in recent work in our laboratory, it has been shown that there were ripening effects at 38°F with 'McIntosh' apples in CA storage when very high levels of ethylene were used continuously. Such high levels would not normally occur in practice.

There are two schools of thought as to whether or not ethylene is a ripening hormone (9). There is strong evidence that it is (18).

Ethylene removal as a means of delaying the ripening of fruits such as mangoes, lemons and bananas needs further study. Air purification with brominated activated carbon has many limitations. Ventilation in sufficient quantity to remove low concentrations of ethylene is expensive because of added refrigeration costs. We have been studying the effect of "Purafil,"[1] alkaline potassium permanganate on aluminum silicate, as a means of removing small quantities of ethylene. In our studies thus far, it looks promising. Unpublished work by G. D. Blanpied and the Atlantic Research Company in our laboratory has shown that the ethylene in a CA room could be burned out by using hydrogen instead of propane in the catalytic burner of CA generator.

Is ethylene the only ripening volatile? It is known that activated coconut shell carbon does not remove ethylene yet air purification with this material has often resulted in delayed ripening of apples (28). What role, if any, do the aldehydes, ketones and alcohols (10 and 16) play in ripening?

Are there ripening inhibitory volatiles? Endogenous ethylene oxide has been found to be a natural antagonist to ethylene in certain products (13). How universal is this compound? Are there other such inhibitors? The vapors of apricots used in sufficient quantity have delayed the ripening of pre-climacteric apples (27). Whatever the inhibitory gases may have been they were removed with activated coconut shell carbon.

Light

There are effects of light on pigmentation of certain fruits after harvest but there is not good evidence that there is any direct effect of light on ripening. We studied the effect of the "Sun Bowl Lamp" on the ripening of pears and bananas and could find no ripening effect.

Conclusion

The postharvest physiologist or technologist may sometimes feel that he has exploited all the environmental factors that may affect ripening. There is still work that can be done.

[1]Courtesy Marbon chemical Company, Washington, West Virginia.

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METABOLIC CONTROL OF RIPENING[1]

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It is generally agreed that fruit ripening is a biologically active process often involving high metabolic activity, increased activity of some enzyme systems, and ultimately in fleshy fruits, deterioration of the organ. These events occur in nature only at the proper physiological stage indicating that natural control systems operate to prevent premature ripening. Because of the dynamic nature of ripening in many species, it is probable that endogenous control systems also function to initiate ripening at the proper stage of ontogeny. The presence of these natural control mechanisms suggest that ripening may be subject to manipulation by horticultural, physiological or biochemical means and indeed, we are becoming increasingly aware of and conversant with concepts and techniques leading to control of this important plant process.

Horticulturists have long shown a keen interest in this area of plant physiology. The high economic value of controlled ripening has led to a great amount of research aimed at environmental control of ripening and storage life of fresh fruits and the future will undoubtedly see continued emphasis in this area. A second reason why horticulturalists have shown such interest in the physiological aspects of ripening is that attempts to control other natural plant processes have led to changes in ripening patterns. Thus, a sizeable section of horticultural literature is devoted to reporting and explaining the effects of stop-drop materials on fruit ripening or the influence of nitrogen levels on ripening and storage behavior, etc.

Obviously, to achieve a high degree of control of ripening of a diversity of fruit species subject to a range of environmental conditions a knowledge of the natural mechanisms of ripening and ripening control would be very beneficial. It is my intention to quickly review some recent developments pertaining to the matter of metabolic control of fruit ripening. Because of the potential breadth of this subject, I will limit the discussion to the subject of metabolic control in climateric fruits. Fruit species catagorized as climacteric fruits have in common a distinct ripening phase characterized by an increase in respiration rate which Kidd and West (10) originally called the climacteric rise in respiration. Another very important common denominator of climacteric fruits is that they respond to and produce ethylene gas. A seriously debated question of many years standing has been: Does ethylene play an essential role in normal ripening? Evidence supporting such a role is weighty. For instance, the presence of ethylene in stimulating quantities at the time of ripening in all climacteric fruits is well documented and the ripening response to enrichment with ethylene is also a matter of record. Furthermore, experiments where endogenous ethylene was removed from the tissue by techniques such as rapid aeration or by subjecting fruit to a partial

[1]Contribution No. 246.