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In Pursuit of a Better Pecan Cultivar

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Abstract

Pecan [Carya illinoensis (Wangenh.) K. Koch] nut yields are low. Except for initial cultivar selections made in the early 1900's, a long-term increase in marketable yield by cultivar improvement has not been documented. Failure of most of the many pecan cultivars is proposed to be due to inadequate testing, overemphasis of precocity and prolificacy, and low market value of the nut. Because pecan fruits are not chemically or mechanically thinned, excessive prolificness and resulting poor nut quality is apparently the predominant reason for failure. The proposal is made that for long-term success, a cultivar should be precocious, but not prolific, and have maximum nut market value (large, early maturing nut, good cracking and shelling characteristics, and a light colored kernel). The vast gene pool in pecan offers the opportunity to engineer a cultivar that will produce nut yields greater than 'Desirable's' (an outstanding cultivar) and maintain the same market value of the nut, or maintain 'Desirable's' yield but increase market nut value, or both. Breeding strategies for obtaining these objectives are proposed.

Introduction

Pecan trees inherently produce low yields as evidenced by the fact that pecan is one of the very few tree crops in which yield per acre is measured in *pounds* instead of *tons*. The average yield is a paultry 850 pounds per acre in the world's center for pecan production located in a 50 mile-radius of Albany, Georgia (36). Although the low yield in the Albany area is partially due to poor tree stands (25), as well as lack of irrigation or inadequate irrigation, the fact remains that the maximum potential yield in pecan is low. Maximum long-term pecan yields range from about 1,500-2,000 pounds per acre depending on the climatic region. However, very few growers achieve these yields on a long-term average. Average yields of 3,000-4,000 pounds per acre are unrealistic with existing cultivars and production technology. Claims of yields of thousands of pounds per acre most often occur in a sale prospectus, in new cultivar releases, during the "on" year of production or in small plots. Such large yields have never been obtained in large acreage on a long-term average.

Attempts have been made to increase yields by cultivar improvement since the late 1800's (3, 18). However, a substantial and long-term increase in yield due to cultivar improvement has not been documented to be greater than that of initial selections ('Desirable,' 'Schley,' 'Stuart' and 'Western Schley') made near the turn of the century. Yield increases during the past 60 years appear to be mainly due, if not entirely, to improved cultural practices.

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Increasing yields in pecan by cultivar improvement is difficult mainly because of the inverse relationship between nut number and quality. The inverse relationship between number and quality was shown by Dodge (5) to occur across cultivars ('Caspiana,' 'Dependable,' 'Mahan,' 'Moore,' 'Sabine,' 'Schley,' and 'Teche') regardless of nut size. Genetically increasing the number of nuts per tree is relatively easy, but maturing the nut of a prolific cultivar with acceptable quality (kernel development) is a major problem. Poor quality from excessive fruiting is circumvented by fruit thinning in fruits such as peaches and apples. However, chemical fruit thinning in pecan is not presently feasible (24) and consequently, as the tree matures, nut quality decreases with prolificness (26). Mechanical fruit thinning (21) may prove to be a means of alleviating this problem.

Most pecan cultivars introduced to date have been unsuccessful. The following discussion is devoted to examining causes of past failures and prevention of future failures. Reasons for cultivar failure and methods to reduce cultivar failure in future releases are examined in the first section. The next section proposes basic objectives that should be the goals of a breeding program to derive a successful cultivar. The third section examines promising current gene pools that could be altered through breeding strategies to produce a successful cultivar. The final section provides a prospectus on the utility of genetic engineering in developing new pecan cultivars.

The proposals presented in this paper are based on published data and in conjunction with my personal observations and analyses of pecan cultivars for the past 27 years. My perceptions on the growth characteristics of cultivars have developed after studying both young and old trees growing over a wide range of climatic, geographic, and cultural conditions. Nut characteristics identified as critical factors affecting market value were confirmed by N. Sachs, Nick Sachs and Co., Inc., Dallas, Texas. Sachs is the major nut broker in the United States and has more than 30 years experience in successful marketing. The proposals are intended to serve as working hypotheses. Hopefully, the ideas presented will generate thought and discussion among pecan workers.

Reasons for Cultivar Failure

Inadequate Testing: Inadequate testing has been the major reason for cultivar failure (Fig. 1). The eventual success of a cultivar has been more or less in direct proportion to either the age of the tree selected from native and seedling populations or to the number of years trees were tested before released. Success in the context of Figure 1 is defined as the ability of a cultivar to produce well-filled nuts as a mature tree. A pecan tree is considered to be mature when nuts are produced in the top of the canopy; i.e., the upper most shoots are no longer vegetative, but are reproductive. In my evaluation of cultivar success (Fig. 1), all other characteristics were disregarded because they become unimportant if the nut fails to fill. The relationship in Figure 1 implies that cultivar testing cannot be complete until the trees are mature and that the minimum testing period should be 20 years or more. However, with the pressure to publish and with the demand for a better cultivar, a 20-year testing period is not likely to occur. The testing period can be shortened by extensively topworking mature trees with the new selection. A selection will respond as a mature tree within about four to seven years after topworking to a mature tree. The time will vary depending on the precocity of the selection. Thus, the performance of the selection at maturity can be evaluated within 10 years instead of 20 or more years as required when grafting to nursery seedling rootstock.

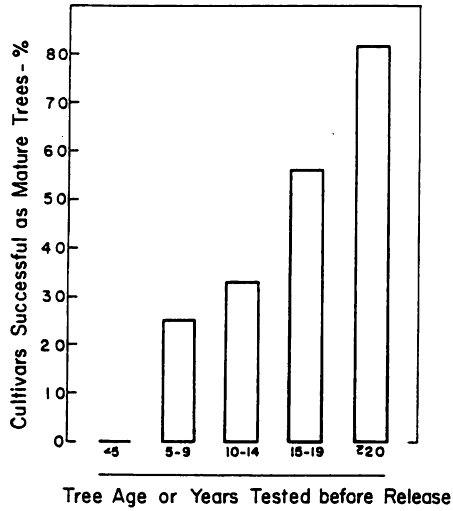

Figure 1. Relationship of pecan cultivar success to tree age or years tested before release. Success is defined as the ability of the cultivar to produce well-filled nuts once the tree matures. Success or failure is based on data from the literature (1, 5, 12, 18, 21, 26, 32) and on observations over a wide range of conditions. Cultivars by age category are: <5 years, 'Texas Prolific'; 5-9 years, 'Mobile,' 'Barton,' 'Cheyenne,' 'Choctaw'; 10-14 years, 'Alley,' 'Curtis,' 'Delmas,' 'Moneymaker,' 'Cherokee,' 'Success,' 'Comanche,' 'Mohawk,' 'Dependable'; 15-19 years, 'GraTex,' 'Stuart,' 'Pabst,' 'Shoshoni,' 'Schley,' 'Mahan,' 'Nelson,' 'Apache,' 'GraBohls'; >20 years, 'Elliott,' 'Burkett,' 'Van Deman,' 'Caddo,' 'Cape Fear,' 'Farley,' 'Gloria Grande,' 'Woodard,' 'Frotscher,' 'Desirable,' 'Tejas,' and 'Osage.' Successful cultivars are 'Elliott,' 'Burkett,' 'Choctaw'(?), 'Van Deman,' 'Caddo,' 'Farley,' 'Gloria Grande,' 'Woodard,' 'Desirable,' 'Tejas,' 'Osage'(?), 'GraTex,' 'Stuart,' 'Pabst,' 'Schley,' 'Apache,' 'Alley,' 'Delmas,' and 'Comanche.' Success is proportional to tree age or years tested, chi square, $P \leq 0.05$.

A grower in Albany, GA, has used topworking to determine selections' ability or inability to fill nuts with kernel once the tree matured. With this method of evaluation, mature trees must be more or less totally converted to the selection. Total conversion requires changing essentially all branches of about 2″ diameter. Because of the exhaustive nature of kernel development (23), conversion of four mature trees should adequately evaluate the selection's ability to fill its nuts. The testing strategy described here differs from the one often used in evaluating progeney of crosses (19) in which case only one or, at most, a few branches are converted. The objective in the latter method is to hasten reproductive maturity to obtain a quick, preliminary evaluation of nut characteristics. Definitive evaluations of the selection as a mature tree should be made with all branches converted. Any potential cultivar should be topworked to mature trees and evaluated before release. Orchard establishment costs (28) are simply too great to plant a cultivar that has not been tested as a mature tree.

Topworking mature trees with a selection will evaluate success as a mature tree; that is, does the mature selection fill the kernel? However, topworking will not evaluate the selection's nut production relative to that of existing cultivars. Thus, in addition to evaluation as a mature tree, the selection should be tested simultaneously relative to industry standards; 'Desirable,' 'Stuart,' and 'Western Schley.' Testing relative to industry standards should be done with transplanted nursery trees. Use of transplanted trees has been recently adopted and comparison with industry standards has been partially adopted by the USDA (34). A minimum of 10 and preferably 20 trees of the standard cultivars and the selections should be included in the test. This sample size was calculated (22) from variability in pecan yields (10, 13) and assumes a detection of a 10 lb. difference in yield per tree. Trials based on low tree numbers (34, 39) cannot be expected to be valid. Furthermore, comparisons should be based on trees planted in the same year. Comparison of trees of the same age but planted in different years (39) does valid comparisons. 'Farley' was tested against trees of the same age but planted in different years and the results led to the erroneous conclusion that yield was high (9). A selection should be discarded if yields do not equal 'Stuart's' by the 10th year from transplanting; otherwise, precocity may be too low for commercial orchards. Any selection with yields equal to or greater than 'Western Schley' is also a potential candidate for discarding because 'Western Schley' is close to or above the upper yield limit at which a mature tree can fill the nut. Whether or not such a selection should be discontinued after 10 years can be determined by evaluation of nut fill following topworking to a mature tree. Obviously, the selection should be discarded if the mature tree does not fill the nut. Selections with yields similar to 'Desirable,' but less than 'Western Schley,' should be given special consideration simply because 'Desirable' is highly successful as a mature tree and is considered by many to be the best cultivar available.

Precocity Overemphasized: The major objective in pecan breeding programs has been on developing precocious and prolific cultivars because of the inherently low yield in pecan. Emphasis on precocity was justified because non-precocious cultivars prolong the slow return (28) on financial investment. However, the close link between precocity and prolificness (26) has resulted in problems in nut quality on mature trees of precocious cultivars. Nut quality is good on young trees of a precocious cultivar because leaf surface is more than ample to supply the nutritional requirements for developing fruit (17); but declining leaf to fruit ratios (20) with tree maturity result in a concomitant decline in the quality of nut produced. Classical examples of cultivars with an inadequate leaf to fruit ratio as a mature tree are 'Chickasaw,' 'Cherokee,' 'Mahan,' 'Mohawk,' 'Moore,' 'Barton,' 'Success,' 'Shoshoni,' and 'Texas Prolific.' This inadequate leaf to fruit ratio of such prolific cultivars is evident in the dramatic improvement in kernel development following fruit thinning (21). Prolific cultivars with acceptable nut quality on mature trees often produce nuts too small (for example, 'Elliott' and 'Tejas') to compete in the marketplace with large, high quality nuts.

The close link between prococity and prolificness and the resulting failure of a precocious cultivar to fill the nuts on mature trees is the major reason for the response in Figure 1. Successful cultivars ('Comanche,' 'Desirable,' 'GraTex,' 'Stuart,' 'Pabst,' 'Schley,' 'Alley,' 'Apache,' 'Van Deman,' 'Farley,' 'Gloria Grande,' 'Woodard,' 'Elliott,' and 'Tejas') included in Figure 1 are either not very precocious or have a small nut. Unsuccessful cultivars ('Mobile,' 'Barton,' 'Cheyenne,' 'Cherokee,' 'Mohawk,' 'Mahan,' 'GraBohls,' 'Texas Prolific,' and 'Success') are very precocious and do not fill the nut after the tree matures and, with some cultivars, before the tree matures. Two basic reasons are responsible for past failures to identify cultivars that would eventually prove to be unsuccessful. First, the inter-relationship of precocity, prolificness, and nut quality (26 had not been established. Second, release of cultivars was based largely on performance as a young tree. Nut quality (nut size and kernel development) is at a peak on young trees. Quality declines with tree maturity; the difference between success and failure is dependent on whether or not quality will decline to an unacceptable level.

Prolificness is a direct function of the density of fruiting shoots, nut size, and number of nuts per cluster. This relationship was confirmed by calculating the mathematical relationship from data of 10 cultivars (31, 32, 38) with a five fold difference in prolificness. The statistical significance relationship; $R^2 = 0.95$, $P \leq 0.05$, is described by the equation:

Prolificness =
-4.3 - 0.804 nuts/lb
+ 57.7 nuts/cluster
+ 0.0132 fruiting shoots/tree.

Thus, maximum prolificness occurs when the number of nuts per cluster and nut size are large and density of fruiting shoots is high as in 'Mahan,' 'Mohawk,' and 'GraBohls.' Conversely, maximization of this combination of characteristics is conducive to minimum nut quality. Observations of a wide range of cultivars suggest a cultivar with a small number of fruits per cluster is the most successful. The classic example of such a cultivar is 'Desirable,' which usually has good to excellent nut quality and return bloom. Based on 'Desirable's' performance, a successful cultivar should have a small cluster size, especially if the nut is large.

Low Nut Market Value: Another problem with pecan breeding and cultivar selection is that insufficient emphasis has been placed on value of the nut in the marketplace. Generally, in the United States, both the price and consumer demand are highest during the early market (mainly gift, Thanksgiving, and Christmas trade) from August through December. In addition, the early market consumes about 67% of the total pecan crop in the United States (N. Sachs, personal communication). Within this market, nut value is largely dictated by nut size, kernel quality including kernel color, cracking and shelling characteristics, and time of nut maturity. Failure to accurately evaluate market value of selections has been due to inadequate testing of the trees under a fruiting stress coupled with a lack of understanding market criteria. The dramatic effect on the market value of the nut can be illustrated by comparing the per acre market value of 'Western Schley' vs. 'Desirable.' 'Western Schley' is a small nut (64 nuts/lb.) and produces a low percentage of intact halves, about 50, upon cracking. 'Desirable' is a large nut (47 nuts/lb.) and produces about 93 percent intact halves (37). A well-managed orchard of 'Western Schley' and an orchard of 'Desirable' should yield 2,000 and 1,400 pounds of nuts per acre, respectively. Assuming 'Western Schley' nuts sell for $0.70 and 'Desirable' for $1.10 per pound (long-term prices supplied by N. Sachs), the gross return per acre for 'Western Schley' (2,000 lbs/acre × $0.70/lb = $1,400/acre) is less than 'Desirable' (1,400 lbs/acre × $1.10/lb = $1,544/acre), in spite of the fact that 'Desirable' produces 600 pounds of nuts per acre less than 'Western Schley.' Pecan nuts are also sold on a kernel point basis. 'Desirable' with 54% kernel would sell for less than 'Western Schley' with 60% kernel if both were otherwise equal in quality. However, even with the exceptional high prices of the 1991 season, 'Desirable,' on a kernel point basis, still grossed more money per acre than 'Western Schley.' This occurred because of the smaller nut (kernel) size of 'Western Schley' and because nuts of this cultivar have poor cracking ability (N. Sachs, personal communication).

Basic Breeding Objectives

There are often many objectives in a pecan breeding (11, 34) but three basic objectives should have priority over others. These three basic objectives are to develop cultivars that a) produce a per acre nut yield greater than 'Desirable' and maintain the same market value of the nut, or b) maintain 'Desirable's' yield but increase nut value, or c) both. Other characteristics, such as scab resistance, are important considerations once the basic objectives are obtained.

High market value nuts must meet the following criteria: a) large size with about 40 to 50 nuts per pound, b) good cracking and shelling characteristics, c) early nut maturity with date equal to or before 'Stuart,' d) light-colored kernels, and e) fruit number per cluster of one to three to insure maximum nut fill. Meeting these criteria would result in a cultivar superior to 'Desirable.' 'Desirable' has big nuts of one to three per cluster, the kernel is well filled and has acceptable color, the nut cracks and shells well, but the nuts of 'Desirable' mature after 'Stuart.'

Developing a cultivar that will produce more nuts that 'Desirable' and with maximum nut market value is the biggest challenge in pecan breeding. The challenge is to somehow circumvent the inverse relationship between nut quality and number of nuts produced (5). Increasing yields while maintaining a constant nut size can be achieved only by increasing the number of fruits per tree. The number of nuts produced on a tree is a direct function of the number of fruits per cluster and the number of shoots producing fruit. Additionally, these two yield components are interdependent (13). Consequently, factors that increase one also increase the other (8) with the net result of increasing fruiting stress. Precocious and non-precocious cultivars differ in the number of fruits per cluster and in the number of fruiting shoots per tree. Generally, fruits per cluster are inherently higher in a precocious than in non-precocious cultivars (30, 38). Precocious cultivars usually have a higher number of shoots than do non-prolific cultivars for a given tree size. For example, calculations from data (31, 32, 38) show that, on the average, mature trees of the prolific 'Robson,' 'San Saba,' 'Teche,' 'Frotscher,' and 'Curtis' have about 50% more fruiting shoots per tree than the non-prolific 'Pabst,' 'Rome,' 'Nelson,' 'Van Deman,' and 'Beverage Triumph.' This difference in number of shoots is apparently due to the more open tree canopy, and thus more interior shoots for prolific cultivars. Consequently, total shoot fruiting, cluster size, and fruiting stress are at a maximum in a prolific cultivar during the "on" year of nut production. Poor kernel quality and low return bloom are reasonable expectations.

Results with the non-prolific and successful 'Schley' suggest that the lower number of fruits per cluster in a non-precocious cultivar is not necessarily due to a lower number of pistillate flowers in a cluster (13). Instead the low fruit number per cluster results from abortion (30) that occurs after bloom. In 'Schley,' the correlation between shoots with pistillate flowers and pistillate flowers per cluster is high at anthesis; but, after the abortion periods, the correlation is low. Final nut yield is more a function of percentage shoots with fruit than fruits per cluster (13). In prolific cultivars, the number of pistillate flowers is equal to or greater than that of non-prolific cultivars. Final fruits per cluster is greater in prolific cultivars due to less pistillate flower and fruit abortion (30).

Breeding Strategies

In theory, increasing the yield per acre of well-developed nuts may be possible if the number of fruiting shoots per tree, but not number of fruits per cluster, is increased. Although this is in direct opposition to the general rule that the number of fruiting shoots and fruits per cluster increase together, breeding may produce an exception. Such a cultivar would have to have three fundamental traits. One, the canopy must be open enough to produce and maintain fruiting shoots within the interior of the canopy. This characteristic would increase the fruiting shoots per tree. Two, the cultivar must have an inherent fruit thinning mechanism. The thinning mechanism would minimize the possibility of over production. Natural thinning during the second drop would be ideal because this drop is apparently independent of cultural practices (29) and occurs before the stress of fruiting (4). Three, cluster size must be large to have one to three fruit per cluster remaining after thinning occurs from the second drop.

In pursuit of these objectives, 'Desirable' would be an excellent parent provided its heavy second fruit drop can be transferred genetically. In addition, 'Desirable' nuts have superior market value. 'Squirrel's Delight,' which also has a heavy second drop, may likewise make a good parent. A number of cultivars with open canopies and profuse interior shoot production are candidates to cross with 'Desirable' or 'Squirrel's Delight.' These include 'Western Schley,' 'Pawnee,' 'Sumner,' 'Apache,' 'Sioux,' 'Moneymaker,' 'Curtis,' and 'Cape Fear.' Of these, 'Western Schley' and 'Curtis' may prove to be poor parents because of the low market value of their nuts. Similarly, 'Sioux' may be a poor choice because of small nut size, although kernel color and overall quality are excellent. In addition, neither 'Western Schley,' 'Sioux,' and especially 'Curtis' have early nut maturity. 'Apache' has marginal nut size, 'Sumner' has good nut size, but both cultivars have late nut maturity. 'Pawnee' and 'Moneymaker' may prove to be very good parents to cross with 'Desirable' and 'Squirrel's Delight.' In addition, 'Squirrel's Delight' may make an interesting cross with 'Cape Fear.'

For early nut maturity, crosses between 'Desirable' and 'Pawnee' may be especially advantageous because of the possibility of the introgression of genes for earliness from 'Pawnee' into the 'Desirable' genome; or, alternatively, the introgression of genes for a small number of fruits per cluster from 'Desirable' into the 'Pawnee' genome. In addition, both cultivars have excellent nut size. Similarly, 'Moneymaker,' because of early nut maturity and extremely open canopy, would make an interesting cross with 'Desirable.' For early nut maturity as such, crosses between 'Squirrel's Delight' and 'Moneymaker' may be especially rewarding. Both cultivars have early nut maturity and, for early maturing cultivars, fair to good nut size. In addition, the heavy second drop of 'Squirrel's Delight' may be transferable, thus producing a manageable cluster size in the progeny. Similarly, transferring the early nut maturity and second drop of 'Squirrel's Delight' to the highly precocious 'Cape Fear' may result in a cultivar with a large, early maturing, high quality nut.

If the number of fruiting shoots can be increased, but cluster size reduced, the result would be a cultivar that is precocious, but not prolific. A disadvantage of such a cultivar is that nut yields as a young tree would be less than in a cultivar such as 'Western Schley' which is both precocious and prolific. The lower yield of the less prolific cultivar could be offset by increasing the number of trees planted per acre. Such would require a tree that is upright and compact, but open. Cultivars with this type canopy are 'Stuart,' 'Sumner,' 'Tejas,' and 'Pawnee.' 'Stuart' may not be a suitable parent because of low precocity. Furthermore, neither 'Sumner' because of late nut maturity nor 'Tejas' because of small nut size may be suitable. 'Pawnee' may be the ideal candidate to cross with 'Desirable' due to 'Pawnee's' early nut maturity and large nut size.

The lower yield of a cultivar that is precocious, but not prolific, could also be offset by increasing tree vigor. The reason for increasing vigor is that yield increases with tree size (2, 35). If all other factors are equal, yield increases faster in a vigorous than in a non-vigorous cultivar. Again, 'Cape Fear,' because of high vigor, may make an interesting cross with 'Squirrel's Delight.'

Genetic Engineering

With genetic engineering, a gene for a specific trait is isolated from a plant or animal and inserted into an organism without the specific gene or genes. In theory, genes for scab immunity in 'Elliott,' for example, could be isolated and then inserted into 'Desirable,' thus making 'Desirable' immune. Similarly, the genes for early nut maturity in 'Witte,' a cultivar with exceptionally early nut maturity, could be inserted into 'Desirable.' In theory, 'Desirable' would then mature nuts in about 140 days rather than 200 days (27) or about two months earlier than normal. The potential implications of genetic engineering are enormous.

Presently, the problem with using genetic engineering in pecan is that genetic information for pecan is almost non-existent (14, 15, 16, 33). Thus, before the genetical engineering potential in pecan can be explored, genes for specific traits will have to be identified. Identification will be a long-term process. Provided genes can eventually be identified and isolated, genetic engineering may prove to be a more feasible method for pecan cultivar improvement than conventional breeding. If so, genetic engineering may also have pitfalls. For example, introduction of excessive earliness into a cultivar with big nuts and high yields may upset the energy balance and synchronization between vegetative and reproductive growth, with the result that the tree may gradually decline once the tree begins to produce nuts.

In addition to the gene pool among cultivars, a vast source of genetic variability exists among seedlings in nature. Desirable trait(s) can easily be found in individual seedlings within this resource. Ironically, this original genetic source, which produced the most successful pecan cultivars, has largely been ignored as it gradually diminishes. Recently, germplasm preservation has become a priority of the Northern Nut Growers Association (6) and the National Plant Germplasm System (7). Preservation is based primarily on seed collection. Although, seed collections may preserve the basic gene pool, the traits within the seeds are unknown. In addition to seed collections, a systematic collection of seedlings with desirable characteristics is needed.

In summary, a vast gene pool exists in pecan. Genotypes already exist with one or more characteristics suitable for a commercially successful cultivar. The challenge is to introgress these characteristics into a common genome.

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Effect of Temperature on Anthocyanin in Apple

Non-bagged and bagged apples (paper bags over fruit) of cvs 'Jonathan,' 'Fuji,' 'Jonagold' and 'Tsugaru' were harvested at different stages of ripening and detached apples irradiated with light at 15, 20 and 25 C. In 'Jonathan' the optimum temperature for anthocyanin accumulation increased from 15 C to 25 C in non-bagged and from 20 C to 25 C in bagged fruit as it ripened. In 'Fuji' and 'Jonagold,' 20 and 15 C respectively were always the optimum for anthocyanin synthesis in non-bagged and bagged apples. In non-bagged and bagged 'Tsugaru,' the optimum temperature increased from 15 C to 20 C with ripening. From Arakawa. 1991. *J. Hort. Sci.* 66:763-768.