FEATURE

The Muscadine Grape: Botany, Viticulture, History, and Current Industry

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The muscadine grape *(Vitis rotundifolia* Michx.) was the first American grape species to be cultivated. This fruit has a long history in commercial and backyard culture. Picking muscadines to enjoy as juice along with muscadine pie on grandmother's back porch has a strong place in childhood memories of many native Southerners. The oldest and most consistent commercial interest in muscadines has been in wine, but juice and fresh fruit markets have also been developed. Muscadines so differ from "bunch" grapes genetically, anatomically,, physiologically, and in taste that they should be considered a separate fruit.

The muscadine industry is currently expanding throughout the southeastern U.S. as interest in grapes and wine increases nationally. Commercial muscadine vineyards range in size from < 1 ha to hundreds of hectares, and may be a primary or secondary source of income to the grower. There is particular interest in this fruit for small and part-time farm operations and as an alternative crop for agronomic growers. An important recent development has been the establishment of a major muscadine juice and processing plant in Mississippi with a satellite plant in North Carolina. Growth of the muscadine industry is supported by research to improve vineyard management, processing methods, and cultivars through breeding.

BOTANICAL BACKGROUND

Most authorities divide *Vitis* into the subgenera *Euvitis* Planch. (the familiar European and American bunch grapes that include *V. vinifera* L. and *V. labrusca* L.) and *Muscadinia* Planch. (sometimes referred to as berry grapes) (Dearing, 1938; Winkler et al., 1974). However, there has been a long-standing controversy, with some authors placing *Muscadinia* as a separate genus (Bouquet, 1980; Olmo, 1986; Small, 1913). Fossil evidence suggests that *Muscadinia* was widely distributed over the North American, European, and Asian continents before the last ice age (Bouquet, 1980). *Thus, Muscadinia* may be an ancestral genus that led to vitis, adapted to temperate climates,. and *Ampelocissus,* adapted to tropical climates, as the ice age receded. A wild grape found in India has similar characteristics to the *Muscudinia* (Syamal and Patel, 1953) and may reflect the pre-ice age distribution of this group.

Muscadinia grapes have 40 somatic chromosomes (2x = 2n = 40) and are characterized by fruit borne in many clusters with few berries per cluster, formation of an abscission zone between the fruit and rachis, smooth thin bark that is adherent on young wood and separates in scales from older wood, unbranched tendrils, dense wood, and continuous pith (L.H. Bailey Hortorium, 1976; Einset and Pratt, 1975; Hedrick, 1908; Munson, 1909; Williams, 1923). In contrast, *Euvitis* grapes have 38 somatic chromosomes (2x = 2n = 38), branched tendrils, many berries per fruit cluster, no abscission zone between the berry and rachis, striated bark on young wood, thick rough bark that peels - in strips on old wood, less-dense wood than *Muscudinia,* and pith interrupted by diaphragms at nodes.

Muscudinia is a much smaller group than *Euvitis,* and is comprised of three known species. *Vitis munsoniana* Simpson ex Munson (common names Bird Grape, Everbearing Grape, Mustang Grape, Little Muscadine Grape) and *V. popenoei* Fennell (common name, Mexican Muscadine Grape) (Munson, 1908; U.S. Dept. of Agriculture, 1973; Weaver, 1976; Winkler et al., 1974) are not important commercially, but are possible sources of genetic variation for breeding programs. *Vitis munsoniana* is likely a semi-tropical variant of *V. rotundifolia,* native to Florida and a narrow coastal band along the Gulf of Mexico from Florida to Texas (Husmann and Dearing, 1916). *Vitis munsoniana* bears clusters of eight to 30 relatively small berries with thin skin and small seeds, but poor fruit quality (Dearing, 1947). *Vitis popenoei* is a tropical species native to southern Mexico (Fennell, 1940).

The third species, *V. rotundifolia* Michx. (common names: Muscadine, Bullace, Bull Grape, Bullet Grape, Southern Fox Grape), is the only commercial *Muscadinia* grape, and the name "muscadine" is reserved exclusively for this species. The majority of *V. rotundifolia* vines in the wild bear dark fruit. A very old name for these grapes is "Bullace" or "Bullis", or less commonly "Bull" or "Bullet" grapes (Gohdes, 1983; Hedrick, 1908). Light-colored bronze-fruited genotypes are occasionally found in the wild and are often referred to generically as "scuppernongs". However, there are many cultivars of bronze muscadines, and 'Scuppernong' is the name of a specific cultivar.

The natural range of *V. rotundifolia* extends from Delaware to central Florida and along the Gulf of Mexico to eastern Texas (L.H. Bailey Hortorium, 1976; Dearing, 1938; Munson, 1909; Weaver, 1976). The species extends north along the Mississippi River to Missouri and near the Appalachian Mountains from the east and west. Temperatures in this region seldom go lower than - 12C and more rarely to - 18C (U.S. Dept. of Agriculture, 1973). These vines do best on fertile sandy loams and alluvial soils, and grow poorly on wet and heavy soils. Natural populations are found in shady, well-drained bottom lands along rivers that are subject to neither extended drought nor waterlogging (Hedrick, 1908; Munson, 1909).

Wild *V. rotundifolia* vines are functionally dioecious (polygamous) due to incomplete stamen formation in female vines and incomplete pistil formation in male vines (Dearing, 1948; Hedrick, 1908). Male vines account for 60% to 75% of the wild muscadine population (Dearing, 1938; Husmann and Dearing, 1916). Female vines bear fruit in numerous clusters of from one to 40, but more commonly four to 10, thick-skinned berries containing two to six large seeds (Husmann and Dearing, 1916; Young, 1920). The vines are late in breaking bud in the spring and require a long season, generally > 100 days, to mature the fruit (Hedrick, 1908).

EARLY MUSCADINE CULTIVARS

Muscadines have long been harvested from wild and semicultivated vines (Hedrick, 1908). According to Hedrick, Native Americans used the fruit, and the earliest Europeans to reach America noted the abundance of *V. rotundifolia.* Captain John Hopkins reported that Spanish missionaries in Florida were making muscadine wine in 1565. He also noted that Amadas and Barlowe reported the abundance of these grapes in coastal North Carolina on their first voyage to this continent in 1584. The latter described the land "so full of grapes . . . on the sand and on the green soil, on the hills as on the plains, as well as on every little shrub as also climbing towards the tops of tall cedars, that I think in all the world the like abundance is not to be found".

Muscadines have been cultivated in vineyards since the mid-18th century (Reimer, 1909). The first cultivars were simply selections propagated from the wild (Reimer, 1909). Although there were 35 to 40 named muscadine cultivars in 1920, only a few were

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grown extensively (Young, 1920). Better-known early cultivars and approximate dates introduced were 'Hopkins' (1845), 'Flowers' (1800), 'James' (1866), 'Memory' (1868), 'Mish' (or 'Meisch') (1846), 'Scuppernong' (mid-1700s), and 'Thomas' (1845) (Husmann and Dearing, 1916; Reimer, 1909). All early cultivars were female types and required pollinator vines for optimum fruit set (Young, 1920).

The cultivar eventually named 'Scuppernong' was the first native American grape to be cultivated (Hedrick, 1908; Reimer, 1909). 'Scuppernong' was the dominant cultivar 'grown from the mid-18th century until as recently as 1947, and it remains the most widely known muscadine (Reimer, 1909; Dearing, 1947; Woodroof, 1934). Popular culture often gives credit for discovery of the original 'Scuppernong' vine to Sir Walter Raleigh's colony when they landed on Roanoke Island, N.C. (Gohdes, 1982; Hedrick, 1908). However, Reimer (1909) concluded that the original 'Scuppemong' vine was found by Isaac Alexander in the mid-18th century along the Scuppernong River in Tyrrell County, N.C. The vine was soon widely propagated and was likely carried to Roanoke Island some time in the late 18th century. This cultivar was initially known by several names, especially the "Big White Grape", and it was not until 1811 that the name 'Scuppernong' was assigned by Calvin Jones, an editor for The Star newspaper of Raleigh, N.C. The name was chosen because of the numerous plantings of this grape along the Scuppernong River and around Lake Scuppernong. The word scuppernong is apparently a corruption of "ascuponung", an Algonquin Indian word for "place of the Sweet Bay plant" *[Magnolia virginiana* L. *(M. glauca* L.)], found abundantly along the Scuppernong River.

'Scuppernong' was especially valued for its hardiness, tolerance of neglect, and quality as a table and wine grape. Bronze muscadines were soon recognized as superior for wine because the nonacylated diglucoside anthocyanin pigments of dark muscadine grapes are unstable and easily oxidized, in contrast to the monoglucoside and acylated monoglucoside anthocyanin pigments of *Euvitis* grapes (Ballinger et al., 1974). Recently, wild muscadine genotypes have been identified with mono- and diglucoside forms of anthocyanin pigments (Goldy et al., 1989). Continuous vegetative propagation of this cultivar for nearly 250 years, and probable introduction of other bronze muscadines under the same name, has resulted in the formation of a number of strains of 'Scuppernong' (Woodroof,. 1934). 'Scuppernong' vines in production have been reported as old as 150 years (U.S. Dept. of Agriculture, 1973).

BREEDING PROGRAMS

Breeding programs to obtain improved cultivars were initiated at Willard, N.C., around 1907 by Dearing (1917) and Detjen (1917a) as a cooperative effort between the USDA-ARS and North Carolina State Univ. and continues today as a university project. A second USDA-ARS muscadine breeding program was conducted at Meridian, Miss., from 1941-1965 by N.H. Loomis. Muscadine breeding was initiated by the Georgia Experiment Station in 1909 (Stucky, 1919). In addition, various private individuals have conducted muscadine breeding efforts, most notably the *Euvitis x V. rotundifolia* hybridization efforts of T.V. Munson (1909) in Texas, and Olmo (1986) and coworkers in California. Active muscadine breeding programs for fruiting cultivars are currently being conducted in Florida (Bates et al., 1980; Mortensen, 1971), Georgia (Lane, 1978), and North Carolina (Goldy, 1988; Goldy et al., 1988). Progress in breeding up to the early 1970s was summarized by Einset and Pratt (1975) and Schwartz (1976). 'Hunt' was introduced in 1920 by the Georgia Experiment Station (Stucky, 1919) and had improved yield and fruit quality, but was female and required companion pollinators. The development of perfect-flowered, self-fertile cultivars was a major goal of early breeding programs. The first self-fertile genotypes were reported by the North Carolina-USDA breeding program in 1917 and the first cultivars were released in 1948 (Dearing, 1917, 1948).

A long-standing goal of both *Euvitis* and *V. rotundifolia* breeding programs has been development of hybrids between these groups, combining fruit quality from *V. vinifera* with disease resistance and environmental adaptation of muscadines (Bouquet, 1980; Einset and Pratt, 1975; Goldy et al., 1988; Lane, 1978; Munson, 1909; Olmo, 1986). Hybridization is difficult due to differences in chromosome number, but has been successful when the muscadine was used as the male parent (Davidis and Olmo, 1964). Most hybrids have been sterile, but a few have a low level of fertility. In addition to standard breeding techniques, tissue culture and protoplast fusion methods are being employed with the hope of developing fruitful hybrids through backcrossing programs to develop both *V. vinifera* and *V. rotundifolia* cultivar types (Goldy et al., 1988; D. Gray, personal communication; Lee and Wetzstein, 1988). No *Euvitis x Muscadinia* hybrids have been released as fruiting cultivars, but two hybrids were recently released as disease-resistant rootstocks for *Euvitis* grapes (Lider et al., 1988a, 1988b; Walker et al., 1989).

The development of a seedless muscadine for table use is a major goal in current breeding programs. Embryo rescue from standard sexual crosses of seedless *Euvitis* grapes (female parent) and *V. rotundifolia* (pollen parent) (Goldy et al., 1988), and protoplast fusion methods (D. Gray, personal communication; Lee and Wetzstein, 1988) are being used in an effort to develop seedless hybrids with *V. rotundifolia* character.

MUSCADINE CULTURE AND PHYSIOLOGY

Propagation. Muscadine grapes are not grown on rootstocks, and are incompatible as rootstocks for *Euvitis* grapes (Davidis and Olmo, 1964; Husmann and Dearing, 1916; Winkler et al., 1974). In contrast to *Euvitis*, muscadines root poorly from woody cuttings (Goode et al., 1982; Husmann and Dearing, 1916). Commercial practice is to propagate either by layering (Woodroof, 1936) or by mist-propagation of softwood cuttings (Goode and Lane, 1983). 1H-indole-3-butyric acid (IBA) increased root system quality of cuttings taken prior to July, but did not increase root initiation or shoot growth (Goode and Lane, 1983). Vines are sold bare-root or in "1-gallon" (3.8-liter) nursery pots. Micropropagation methods are currently being developed by several groups (Gray and Fisher, 1985; Griffin and Graves, 1989; Lee and Wetzstein, 1989; Sudarsono and Goldy, 1988).

Planting and establishment. General recommendations on site selection, soil preparation, planting methods, and vineyard management are given in several muscadine production manuals (Hegwood et al., 1983; Ferree et al., 1983; Poling et al., 1987; U.S. Dept. of Agriculture, 1973). While mature muscadine vines are noted for vigorous growth, they can be difficult to establish after planting (Husmann and Dearing, 1916). Recent studies have determined that size, shape, and wall roughness of the planting hole, and severity of summer pruning in first-season vine training, have a marked effect on establishment and growth of muscadines (Olien, 1989).

Training and *trellis.* Traditionally, muscadines were grown on extensive overhead arbor systems, often without pruning or management (Husmann and Dearing, 1916; Newman, 1907). Arbor height was typically 2.1 m, with eight arms radiating out from single trunks, spaced at 4.6 x 4.6 m. Newman (1907) recommended a four-wire vertical trellis (4-WVT) over the arbor system for commercial production because it was easier to manage and harvest. However, the vigorous growth habit of muscadines soon led to recommendations of two or three wires in vertical systems to reduce shading of lower cordons and consequent increase in growth, yield, and fruit quality (Dearing, 1938; Husmann and Dearing, 1916; Savage, 1941; Young, 1920). Generally recommended spacing was 6.1 to 6.7 m in-row and 3.7 to 4.6 m between rows. In a 20-year study, Brightwell and Austin (1975a) found that long-term yields of 'Hunt' were lowest on single-wire trellis, intermediate on a 2-WVT, and highest on the arbor system, if managed with adequate pruning. However, highest yield in the first two bearing years was obtained with the 2-WVT system, an important advantage in generating income to offset establishment costs. In-row vine spacing from 6.1 to 6.7 m had no effect on yield/area, but between-row spacing of 3.0 m gave higher long-term yields/area than either 3.7 or 4.3 m between rows (Austin and Bondari, 1989; Brightwell and Austin, 1975b). When a two-wire horizontal trellis, based on Geneva Double Curtain (GDC), was compared with 2-WVT, the GDC system averaged 11% greater yields and 0.6°Brix higher soluble solids for 31 cultivars over the first 3 to 5 crop years (Andersen et al., 1985; Andrews, 1981). R.P.

Lane (personal communication) noted a 63% yield increase for GDC over a single-wire trellis, but pruning costs were 29.7 and 7.4 working hours/ha (12 and 3 hr/acre), respectively. Muscadines grown on GDC are not maintained as two separate "curtains", but shoots from parallel cordons are allowed to grow together. This arrangement creates a shaded, humid canopy in the fruiting zone and in some regions results in an unacceptable amount of fruit rot (G.W. Krewer, personal communication). Some growers have hedged the lateral shoots to near the fruiting zone soon after veraison to aid spray penetration and decrease canopy humidity. There have been no research evaluations of the possible benefits or hazards (such as increasing risk of fall cold injury) of this practice. Leaf removal has become a standard practice to reduce canopy density of bunch grapes (Winkler et al., 1974), but this has not been tried in muscadines.

In current commercial production, muscadines are trained to single trunks with permanent cordons on 1- or 2-WVT or on GDC. The most common spacing is 3.7 m between rows × 6.1 m in the row. Optimum trellis design and training system depends on a balance of management costs, yield, and price per tonne of fruit. The GDC system is recommended in Mississippi (C.P. Hegwood, personal communication), while the single-wire trellis is most commonly recommended in Florida, Georgia, and the Carolinas (R.G. Goldy, R.P. Lane, and J.A. Mortensen, personal communication).

Management of fruiting wood. Dormant pruning was originally believed to be injurious, but several early authors disputed this claim (Husmann and Dearing, 1916; Newman, 1907; Reimer, 1909; Young, 1920). According to Dearing (1938), lack of pruning decreased fruit quality and increased alternate bearing, early defoliation, and susceptibility to winter injury. Late winter or early spring pruning results in highly visible "bleeding" of sap from pruning wounds. Newman (1907) noted heavy bleeding in vines pruned in February or later and recommended pruning earlier than this, believing that excessive bleeding is detrimental. He collected as much as 1.5 kg of sap per vine over 2 months from vines pruned 20 Mar. Late pruning has been reported to delay shoot and berry development and reduce yields (Newman, 1907; Onokpise and Inyang, 1987), but others found no decrease in yield with late pruning (Dearing, 1938; Loomis, 1943). Dearing (1938) concluded that pruning should be confined to the period between mid-winter and bud swell. Increased susceptibility to winter injury has been noted following pruning before mid-winter (Dearing, 1938).

Early publications recommended pruning muscadines to short spur systems on permanent cordons. (Armstrong et al., 1934; Murphy et al., 1938; Savage et al., 1941), but supporting data were lacking. Loomis (1943) found higher yields in a 3-year trial when mature 'Scuppernong' and 'Thomas' vines were pruned to four-bud spurs in comparison to pruning to a six-cane Kniffen system with 2.3-m canes. In a 5-year study, there was no effect on yield when mature 'Thomas' were pruned to one-, two-, three-, or four-bud spurs or for mature 'Hunt' pruned to two- to four-bud spurs, with and without 50% spur thinning, or to seven- to eight-bud canes (Loomis et al., 1949). Lane (1977b) compared 10 cultivars over the first five fruiting years pruned to three-bud spurs or nine-bud canes, with equal number of buds retained in each treatment. Yield of vigorous cultivars was consistently greater with cane pruning. Other cultivars showed an occasional yield increase with cane pruning, but spur pruning was never superior in these young vines. Higher yields with cane pruning were a result of greater bearing surface. Results of this study also indicated the onset of alternate bearing in cane-pruned vines after the fourth treatment year. Annual pruning must be accompanied by regular spur thinning. Excessive spur development over several years leads to shading, poor canopy structure, and poor fruit quality, similar to the problems with no pruning (Lane, 1977b; Loomis et al., 1949).

Current practice is to prune to two- to four-bud spurs, up to six-bud spurs for vigorous shoots, in combination with occasional light spur thinning (Hegwood et al., 1983; Ferree et al., 1983; Poling et al., 1987; U.S. Dept. of Agriculture, 1973). Mechanical hedging with follow-up hand-pruning is practiced by growers with large operations. Mainland et al. (1982) reported that hedging a 20 × 20-cm square around the cordon without additional hand-pruning resulted in increasingly dense growth over 3 years that made harvest difficult. However, hedging to 20 × 40-cm and alternating the long axis between a horizontal and vertical direction each year maintained a manageable canopy without decreasing yield.

A further important task of dormant-pruning is removal of tendrils that encircle cordons or spurs. Muscadine tendrils become extremely tough and will girdle spurs and even the main cordon if not removed each year. Yield increases associated with pruning will be lost if equal care is not given to removal of circling tendrils (Hegwood et al., 1983; Ferree et al., 1983; Poling et al., 1987; U.S. Dept. of Agriculture, 1973).

New shoot growth and fruiting wood must be prevented from developing on the permanent trunk and arms leading up to the trellis wires, particularly for efficient mechanical harvest. An exception is the occasional need to train replacement trunks or cordons. Dearing (1938) recommended regular, systematic replacement of cordons over an 8-year period. New shoot growth is easily rubbed off by hand in the spring and early summer. Naphthaleneacetic acid in white latex paint has been used successfully to prevent shoot development on established trunks, while physical wraps prevented shoot development but induced root development on the trunk (Takeda et al., 1983).

Pollination and fruit set. Small vineyards of female cultivars might depend on male vines in adjacent woods, but commercial production of such cultivars requires planting male vines every third vine in every third row (Husmann and Dearing, 1916). Thus, before the development of perfect-flowered cultivars, 11% of the vineyard was occupied by nonbearing vines. Today, perfect-flowered cultivars are used as pollinizers, greatly increasing yields per hectare.

Muscadines pollen is dry and is probably transferred to pistillate cultivars almost entirely by insects (Dearing, 1938; Detjen, 1917b). Dearing (1938) reported that the most efficient pollinator is the small mining bee (*Halictus stultus* Cress.), followed by the green bee (*Agapostemon splendens* Lep.), gray bee (*Magachile* sp.), and small bumblebee (*Bombus irnpatiens* Cress.), and that the honeybee (*Apis mellifica* L.) is not an efficient pollinator of muscadines. Beetles have also been noted as possible muscadine pollinators, particularly *Copidita thoracica* F. and the soldier beetle (*Chauliognathus marainatus* F.) (Dearing, 1938; Detjen, 1917; Armstrong, 1936). Dearing (1938) estimated that fruit set of pistillate cultivars was normally 7% to 10%, but could be increased to 20% to 30% with proper pollination. The primary means of pollen transfer in perfect-flowered muscadine cultivars is not known. Winkler et al. (1974) concluded that self-pollination is the primary method of pollen transfer in *V. vinifera* grapes, and that insect and wind transfer of pollen were relatively unimportant. Various beetles and flies, but not bees, have been noted at anthesis in muscadine test vineyards in North Carolina (R.G. Goldy, personal communication). Fruit set in six perfect-flowered muscadine selections ranged from 11.3% to 23.3% (Goldy, 1988).

An initial set of berries develops opposite leaves at nodes 3 through 6 from the base of current season shoots, as in many grapes (Pratt, 1971). However, muscadines have a marked tendency to develop additional flower buds on lateral shoots that can flower and set fruit in the year they are initiated (Husmann and Dearing, 1916; Young, 1920). This tendency results in uneven ripening with fruit ranging from a few millimeters in diameter to fully mature at harvest. Berries from the initial fruit set ripen earliest and have the highest quality. The degree of secondary fruit development is affected by cultivar, vine age, management practices, and environmental conditions.

Fruit development. Muscadine berries appear to develop in the same manner as *Euvitis* grapes, following a double-sigmoidal growth curve (Carroll, 1985; Pratt, 1971). Sugar content and pH increase and acid content decreases as berries mature (Carroll, 1985). Although fruit size at maturity differs considerably with cultivar, perfect-flowered types tend to be smaller (average 4.7 g/berry, ranging from 2.2 to 7.4 g/berry) than pistillate-flowered types (average 5.8 g/berry, ranging from 2.8 to 15.0 g/berry) Andersen et al., 1985; Balerdi and Mortensen, 1969; Carroll, 1985; Hegwood et al., 1983; Moore and Bowden, 1976; Poling et al., 1985; Williams, 1954).

Muscadine berries form an abscission zone between the fruit and rachis (Sherman, 1963; Mitchell, 1979). In most cultivars, the berry matures before this abscission layer is fully formed, although there is variation among cultivars and years (Sherman, 1963). Fruit removal force has been positively correlated with juice soluble solids content in **'Carlos',** 'Magnolia', 'Tarheel', and 'Noble' (Mitchell, 1979). When harvested, immature fruit abscission zones tend to tear, resulting in a "wet stem scar", tom skin, and leaking juice. Fruit in this condition deteriorate and decay rapidly. 'Carlos' is the best cultivar developed to date for stem scar rating, usually 10% wet scar at harvest, and is often used as the standard for evaluating new cultivars (Lane, 1977a, 1980; Lane and Bates, 1987; Mitchell, 1979). Other cultivars with high dry stem scar ratings are 'Golden Isles' (Lane and Bates, 1987), 'Southland' (Hegwood et al. 1983), 'Summit' (Lane, 1977a), 'Triumph' (Lane, 1980), and 'Thomas' (Sherman, 1963). 'Tarheel' tends to be intermediate in stem scar rating (Mitchell, 1979).

Harvest. With good vineyard management, muscadines will produce a commercial yield in the third year after planting and mature yields by the 6th to 7th year (Dearing, 1938). Because of the tendency to shatter (abscise), muscadines are usually harvested as single berries (Mitchell, 1979). However, whole clusters of cultivars with less tendency to shatter, such as 'Fry' and 'Pride', may be clipped by hand for the fresh market (Lane, 1972). Traditionally, muscadines are harvested semimechanically. The trellis and vine arms are beaten with baseball bats, shaking the fruit off the vine onto-a tarp or canvas frame (Clark, 1981; U.S. Dept. of Agriculture, 1973). This method can damage the vine and fruit. Fruit bruised and covered with leaking juice due to harvest injury must be processed or sold fresh within a few days. Most mechanical harvesters operate in a similar manner to the semimechanical method and cause similar problems. A new mechanical harvester for muscadines is under development at Mississippi State Univ. This harvester vibrates the vine arms, rather than beating them, and shows promise for both processing and fresh-market muscadines. (2-Chloroethyl)phosphonic acid (ethephon) has been used successfully as an aid to mechanical and semimechanical harvest of muscadines by promoting development of the fruit abscission layer (Lane and Flora, 1979; Mortensen, 1980; Phatak et al., 1980).

Average harvest date across all cultivars ranges from 24 Aug. in central Florida to 15 Sept. in Mississippi, Georgia, and the Carolinas (C.P. Hegwood, R.P. Lane, and J.A. Mortensen, personal communications). The period from flowering to harvest is fairly constant across production areas, varying from 106 to 113 days. Individual cultivars vary considerably in average harvest date, providing a harvest season of »30 days.

Fruit yield. -Early in this century, yields of mature muscadine vines averaged 6.7 to 10.1 $t \cdot ha^{-1}$, and ranged from 4.4 to 17.9 $t \cdot ha^{-1}$ depending on site, season, care, and cultivar (Husmann and Dearing, 1916). 'Scuppernong' was noted to produce low yields, averaging 5 $t \cdot ha^{-1}$. Despite changes in cultivars and management practices, the average commercial yield has remained relatively unchanged. Yields over the southeastern United States were reported to average 4.4 to 9.0 $t \cdot ha^{-1}$ in 1973 (U.S. Dept. of Agriculture, 1973). North Carolina reported yields of 7.8 $t \cdot ha^{-1}$ as recently as 1982 (Poling, 1982). However, many growers are achieving regular yields of 22 $t \cdot ha^{-1}$. Yields in published cultivar trials vary widely, but better-yielding cultivars generally range from 11 to 34 $t \cdot ha^{-1}$ at a vine spacing of 3.7 × 6.0 m (e.g., Andersen et al., 1985; Balerdi and Mortensen, 1969; Goldy, 1988; Hegwood et al., 1983; Moore and Bowden, 1976). Yields of 'Doreen' have been recorded as high as 40 $t \cdot ha^{-1}$ in cultivar trials (Hegwood et al., 1983).

Fruit quality and juice yield. Due to uneven ripening, methods of fruit sorting and grading would be particularly advantageous for fresh market sales. Successful grading into ripeness categories has been accomplished by a reflected light spectrophotometer (Ballinger et al., 1978) and by density separations in graded brine solutions (Lanier and Morris, 1979).

Factors affecting quality of juice, wine, and fresh use, and yields of juice per weight of berries, were recently reviewed by Carroll (1985). Muscadine juice tends to be lower in soluble solids concentration (SSC) and titratable acidity than *V. labruscana* and *V. vinifera* juice (Carroll, 1985). Sugar and acid frequently must be added to the juice to produce a wine with sufficient acid and alcohol content. Carroll (1985) listed major juice components and average concentrations for muscadine cultivars in current production as fructose (5.51%), glucose (5.16%), sucrose (1.89%), malic acid (0.50%), and tartaric acid (0.36%). Soluble solids concentration averaged 13.2% (10% to 18%), titratable acidity (expressed as tartrate equivalent) 0.84% (0.39% to 1.5%), and pH 3.14 (2.9 to 3.4). As with other American grapes, the significant sucrose content of muscadine juice is in contrast to the trace concentrations of sucrose in *V. vinifera* grapes. Grower contracts for sale of muscadines for juice production specify SSC of 13% to 15%, with premiums paid for SSC up to 18% (R.T. Kahrer, personal communication). No mention is made of juice pH or titratable acidity. Flavor components are more highly correlated with juice pH than with titratable acidity or SSC (R.P. Vine, personal communication). Carroll (1985) stated that total acidity and pH are probably more critical than sugar content as a harvest index for wine production. He recommends harvesting at a total acidity above 0.5% and pH of 3.0 to 3.4. Bates et al. (1986) recommend muscadine harvest for wine before full maturity with juice pH of 3.0 to 3.5. Harvesting by pH alone in the range of pH 3.1 to 3.3 has been recommended for unfermented juice (R.P. Vine, personal communication).

Low juice yields per tonne of fruit due to thick skins and mucilaginous pulp is a second problem in processing muscadines (Harkness et al., 1987; Sims et al., 1988). Juice yields of muscadines range from 46% (w/w) to 54%, as compared to 67% to 75% from 'Concord', using conventional crushing and pressing methods (Harkness et al., 1987). Effects of temperature during pressing and pressing aids (e.g., rice hulls) are being evaluated as a means to increase muscadine juice yield while maintaining juice quality (Harkness et al., 1987; Sims et al., 1988).

Vineyard floor management. Herbicide weed control in the row with grass alleys between rows has become standard practice, but bare soil can create problems in highly erodible sites. Early muscadine bulletins recommended intercropping "hoed" crops such as melons, tomatoes, peanuts, cotton, tobacco, and legume crops to add income, especially during the 3 to 5 years before significant 'yields were obtained from the muscadine vines (Husmann and Dearing, 1916). Cereals and corn were not recommended. Frequent cultivation has been used to develop a deep root-system, but this practice is no longer recommended because muscadines tend to be very shallow-rooted, even in well-drained soils. Current research on intercropping is being conducted to aid small farmers (O. Bandele, personal communication). Interplanted clover is also being explored as a mulch and N source (C.P. Hegwood, personal communication).

Irrigation and fertility. Irrigation has been recommended only recently in the mid-Gulf of Mexico region (Hegwood et al., 1983), and is not common in the Carolinas and Georgia (Ferree et al., 1983, Poling et al., 1987). Austin and Bondari (1988) found considerable variation in yield response of mature 'Hunt' vines to drip-irrigation over 8 treatment years, and a significant interaction with fertility level. Yields of nonirrigated vines fertilized annually with 1.4 kg/plant of 10N-4P-8K fertilizer were not significantly different from vines irrigated to maintain soil water potential > 15 kPa at 15- and 45-cm depths and fertilized with 0.9 kg/plant of the same fertilizer. Irrigation markedly reduced alternate bearing.

Where used, irrigation is almost exclusively applied through drip systems. Irrigation is particularly important during the first 2, years to hasten vine establishment and training (Hegwood et al., 1983). Bearing vineyards should be well-irrigated during the first part of the season to support shoot growth, flowering, and initial fruit set. However, after set of the primary crop, irrigation should be limited during the remainder of the season to reduce secondary fruit set and uneven ripening and to reduce late-season shoot growth, delayed dormancy,and susceptibility to winter injury.

Fertilizer recommendations for muscadines have been largely based on bunch grape practices (Hegwood et al., 1983; Ferree et al., 1983; Poling et al., 1987; U.S. Dept. of Agriculture, 1973). Muscadine fertility research prior to 1966 was largely concerned with Mg deficiency (Cook, 1966). Much of the muscadine production is on sandy soils with low cation exchange capacity and low Mg levels. Muscadines are particularly prone to Mg deficiency, and symptoms of interveinal leaf chlorosis are frequently apparent from the middle to end of the growing season

(Lott, 1948; Hagler, 1949). The problem can be corrected by soil amendment, foliar application, or trunk injection of $MgSO_4$ (Lott, 1948, 1952), but best results were obtained by foliar sprays of $MgCl_2$ and $Mg(NO_3)_2$ (Hagler, 1957). Apparent yield responses to B application have been noted in Georgia, (Boswell et al., 1980). Ragland (1940) noted response to potash, but not nitrate or P, in reversing symptoms of leaf yellowing and scorch in a mature muscadine vineyard. A series of papers by Cummings and co-workers in North Carolina reported considerable variation in leaf and fruit nutrient content through the season and between years (Cummings and Lilly, 1984, and papers cited therein). Optimum yields occurred over soil pH values of 5.5 to 7.0, and yield was increased at all pH levels by increasing annual N application from 50 to 83 $kg \cdot ha^{-1}$ (Cummings and Lilly, 1984).

Diseases and pests. Muscadines have a high degree of resistance to pests and diseases, especially Pierce's disease *(Xylella fastidiosa* Wells et al.), which severely limits production of *Euvitis* species in the southeastern United States (Bouquet., 1980; Hedrick, 1908). *Vitis rotundifolia* is among the most resistant grape species to the grape phylloxera insect *(Daktulosphaira vitifolia* Fitch), which causes devastating root injury to *V. vinifera* (Husmann and Dearing, 1916). Muscadine pests noted early in this century were black rot *[Guignardia bidwellii* (Ellis) Viala & Ravaz] and grapevine flea beetle *(Altica chalybea* Illiger) (Husmann and Dearing, 1916). As muscadines became more extensively planted, additional pests were recognized. Excellent descriptions of muscadine diseases and pests are contained in references by Pearson and Goheen (1988), McGiffen and Neunzig (1985), and Dutcher et al. (1989).

Primary disease problems of muscadines are fruit rots, especially black rot, bitter rot *[Greeneria uvicola* (Berk. & Curt.) Punithalingam, syn. *Melanconium fuligineum* (Scribner & Viala) Cav.], ripe rot *[Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc., teleomorph *Glomerella cingulata* (Stonem.) Spauld. & Schrenk], and macrophoma rot *[Botryosphaeria dothidea* (Moug. ex Fr.) Ces. & de Not., anamorph *Macrophoma* sp.] (Ferree et al., 1983; Hegwood et al., 1983; Jabco et al. 1985; Poling et al., 1987; Savage, 1941). If severe, angular leaf spot *(Mycosphaerella angulata* Jenkins) may cause leaf abscission, resulting in smaller berries and lower sugar content than from healthy vines. Powdery mildew *[Uncinula necator* (Schw.) Burr.] has been reported as a problem on .'Magnolia', 'Regale', and 'Tarheel' in Georgia and North Carolina (Lane, 19776; Poling et al., 1985). These diseases have been controlled with cultural practices and fungicides, although the number of fungicides registered for use on muscadines has decreased in recent years.

Muscadines are more resistant to Pierce's disease *(Xyella fastidiosa* Wells et al.) than *Euvitis* grapes, but the disease has been noted in muscadines and has been associated with vine death in some cases (Hopkins et al., 1974). The causal organism of crown gall *[Agrobacterium tumefaciens* (E.F. Smith & Townsend) Conn. Biovar. 3] has been found as a latent, systemic infestation in nearly all muscadines vines tested (Griffin and Graves, 1988). However, actual gall formation and associated vine injury or death are generally only induced after winter injury and are not frequently observed. The disease is most apt to be a problem where low winter temperatures are limiting. No practical controls exist for Pierce's disease or crown gall. Virus diseases have not been reported in muscadines, but it is likely that they occur.

Insect control is primarily limited to grape root borer *(Vitacea polistiformis* Harris) (Dutcher et al., 1988; McGiffen and Neunzig, 1985). Control of this pest is extremely difficult because of the subterranean feeding of larvae on roots and the lack of distinct early symptoms (All et al., 1987). Early claims that muscadines were immune to grape root borer have been shown to be erroneous. No complete control strategy has been developed, but partial control is achieved with a soil drench of chlorpyrifos insecticide (Lorsban-4E, Dow, Midland, Mich.) around the trunk, in combination with cultural practices such as weed control and temporary soil mounding (All et al., 1987). Pierce's disease is vectored by sharpshooter leafhoppers (family *Cicadellidae,* subfamily *Tettigelinae),* but control of these insects is difficult (Pearson and Goheen, 1988). Other pests, such as mites, aphids, grape flea beetle *(Altica chlybea* Ill.), grape curculio *(Craponius inaequalis* Say), and grape berry moth *(Endopiza viteana* Clemens) are occasional problems and are controlled only if significant injury is observed (Hegwood et al., 1983; Ferree et al., 1983; Poling et al., 1987; Savage, 1941).

HISTORY OF PRODUCTION AND USE

The muscadine industry has experienced fluctuations closely tied to sales of muscadine wine (Gohdes, 1982; Morton, 1988; Reimer, 1909). In 1810, Washington County, N.C., produced 5176 liter (1368 gallons) of wine from native grapes, most of it from 'Scuppernong' (Reimer, 1909). The industry continued to grow, with vineyards in North Carolina as large as 243 ha (Reimer, 1909). Until national prohibition, ≈60% of total muscadine production was used for wine (Gohdes, 1982; Husmann and Dearing, 1916). "Virginia Dare", produced by Paul Garrett, was the most popular wine in the United States before prohibition (Gohdes, 1982). This wine was initially pure muscadine, but later became a blend of muscadine and California *V. vinifera.* The influence of Garrett on the muscadine industry is described by Gohdes (1982). Adoption of prohibition, first at the state level, and then nationally in 1919 with passage of the Volstead Act and the 18th Constitutional Amendment, brought an end to commercial wine production (Gohdes, 1982). However, increased demand for home wine making actually led to a boom in both East and West Coast grape production. The boom lasted until 1926, when grape prices dropped due to over-production, which was followed by the Great Depression, when many vineyards were abandoned. National prohibition ended in 1932 with adoption of the 21st Constitutional Amendment, but prohibition forces remained strong in the South and the muscadine industry did not rebuild. In 1935, the Federal Emergency Relief Administration began a program to promote muscadine fruit and wine production as an aid to Southern families on Rural Relief and to agronomic growers facing economic disaster with cotton, tobacco, and other crops (Gohdes, 1982). The plan called for planting 2 million vines. The problems of mass propagation on this scale were described by Woodroof (1936). Some of these grapes were planted and brought into production; however, the program as a whole-was not successful and was strongly opposed by prohibition forces.

Significant expansion of muscadine acreage occurred in the early 1960s and continued through the early 1980s with increased national consumption of wine (Brooks, 1978; Gohdes, 1982; Poling et al., 1987). Again, muscadine production, principally for wine, was seen as a means to aid depressed state economies and as a profitable alternative crop for agronomic growers. In 1965, North Carolina appropriated funds to stimulate research on breeding, production, and marketing of muscadines (Gohdes, 1982). Muscadine vineyards in North Carolina increased from 240 ha in 1968 to >1000 ha in 1976. In 1978, muscadine production in Georgia and South Carolina included 300 and 200 ha, respectively, with less production in Alabama, Arkansas, Florida, and Mississippi (Brooks, 1978). Major commercial use of muscadines remained wine production, but fresh fruit sales were increasing in importance. As recently as the early 1970s production in Georgia and the Carolinas depended on the old cultivars Hunt, Scuppernong, and Thomas (U.S. Dept. of Agriculture, 1973). With expansion of the industry, the leading cultivars in North Carolina shifted by 1976 to 'Carlos' (47%), 'Magnolia' (20%), and 'Scuppernong' (12%), followed by 'Fry', 'Higgins', 'Hunt', and 'Noble' (Gohdes, 1982). Prices paid for fruit by wineries declined and muscadine production in North Carolina fell to 688 ha by 1981 (Poling et al., 1987). The important cultivars in North Carolina in 1985 were the same as in 1976, but 'Magnolia', and especially 'Scuppernong', were decreasing in importance (Poling et al., 1985). Carroll (1985) recently estimated that bronze cultivars grown for wine made up 96% of North Carolina production. In 1980, fresh fruit was reported as the primary use for muscadines in Georgia, based largely on 'Fry' (Phatak et al., 1980). Recent development of a major juice plant in Mississippi has provided an additional stimulus to the muscadine industry. Production in Mississippi increased from 45 ha in 1984, primarily for small wineries, to ≈340 ha in 1988 (G. Feltenstein, personal communication). Expansion of muscadine vineyards is continuing in Mississippi and is expected to exceed 500 ha in 1990. Total grape production (bunch plus muscadine) in Arkansas, Georgia, North Carolina, South Carolina, and Missouri averaged 14,800 t/year during 1984 through 1986 (U.S. Dept. of Agriculture, 1987), which represented 0.3% of total U.S. production, or 11% of grapes produced in Eastern states.

Table 1. Current muscadine production in 15 southeastern states.[z]

Region/state	Muscadine grapes (ha)	Bunch grapes (ha)	Total grapes (ha)
Coastal states			
Alabama	146	16	162
Florida	223	182	405
Georgia	364	162	526
Louisiana	81	0	81
Mississippi	243	0	243
North Carolina	268	28	296
South Carolina	202	101	303
Subtotal	1527	489	2016
Percent	76	24	
Interior states			
Arkansas	40	1275	1315
Kentucky	0	40	40
Missouri	0	607	607
Oklahoma	0	61	61
Tennessee	18	93	111
Texas	20	1882	1902
Virginia	4	494	498
West Virginia	0	4	4
Subtotal	82	4456	4538
Percent	2	98	
Total, all southeastern United States	1609	4945	6554
Percent	25	75	

[z]Information based on responses of muscadine researchers and extension specialists surveyed in each state.

SURVEY AND CURRENT STATUS OF THE MUSCADINE INDUSTRY

I conducted a survey in 1988 to gain a more detailed picture of the bunch grape and muscadine grape industries in the southeastern United States, Experiment station researchers and extension specialists dealing with grapes in 15 states (Table 1) were contacted and asked to provide the following information for each state: 1) An estimate of the number of hectares producing muscadine and bunch grapes; 2) the most common muscadine cultivars grown; 3) primary uses and markets for grapes; and 4) primary problems of the muscadine and bunch grape industries.

Muscadine hectarage in the southeastern United States is estimated at > 1600 ha, 25% of the total *Vitis* hectarage in these states. Interior southeastern states have more than twice the hectarage of all grapes as that in coastal states. Muscadine production is concentrated in the coastal states, accounting for 2% of the total grape hectarage in interior states and 76% in coastal states. States with > 200 ha of muscadine grapes were (most to least) Georgia, Mississippi, North Carolina, Florida, and South Carolina. Major bunch grape-producing states in the South are Texas, Arkansas, Missouri, and Virginia, with major emphasis on *V. vinifera* for wine production. In general, muscadines are grown where Pierce's disease is limiting and American and French-American hybrid *Euvitis* grapes are grown where cold injury is limiting. *Vitis vinifera* is preferred because of greater profitability in wine production and is grown where neither Pierce's disease nor cold injury is limiting.

A quantitative comparison of relative cultivar importance is not possible because muscadine production and hectarage statistics for the region are not available. However, cultivars were grouped qualitatively, based on the number of states listing each cultivar as important (Table 2). Currently, the two most important cultivars are 'Carlos' and 'Magnolia' (Group A). Nine additional cultivars also ranked highly, being listed in five to six states (Group B) or three to four states (Group C). The 14 cultivars in Group D were listed in commercial production in one or two states. Not listed are many cultivars that are in minor commercial production or are grown in backyards. Many newly released cultivars are being planted and will change cultivar ranking in the future. 'Doreen' is a new cultivar increasing in importance, while 'Hunt', 'Magnolia', and 'Scuppernong' are examples of important older cultivars that are being replaced. 'Fry' remains the primary cultivar for fresh-market production. Current expansion of muscadine production in Mississippi is based heavily on 'Carlos' and 'Doreen', but many other cultivars are also being planted. Primary characteristics and uses of the more-important or well-known cultivars are summarized in Table 3. Current problems and strengths of the muscadine-industry are summarized in Table 4. Many of the environmental and marketing problems listed are also factors limiting bunch grape production.

Commercial interests continue to demand improved cultivars and cultural methods for muscadine production. Cultural methods developed for bunch grapes often cannot be directly applied to muscadines due to marked genetic differences between *Muscadinia* and *Euvitis.* Continued commercial development depends heavily on research to improve production and processing methods, and to develop superior cultivars for fresh market and for processing. Work with *Muscadinia* x *Euvitis* hybrids will also be important in developing new rootstock and fruiting cultivars for both bunch grape and muscadine production.

Table 2. Primary muscadine cultivars grown by state.[z]

Group[y]	Cultivar	Alabama	Florida	Georgia	Mississippi	North Carolina	South Carolina	Tennessee	Texas	Virginia
A	Carlos	*	*	*	*	*	*		*	
	Magnolia	*	*	*	*	*	*			*
B	Fry	*	*	*	*	+			*	
	Higgins	*		*	+	+			*	
	Sugargate	+	+		+				*	*
	Summit	*	*	*	+				*	
C	Cowart	+		*					*	
	Doreen				*	+			+	
	Hunt	+		+		+				*
	Jumbo	+	*	*	*					
	Noble	+	*		*	*				
D	Albemarle					+				
	Dixie		*			+				
	Dixiered		*		+					
	Farrer		+							
	Granny Val		+							
	Nesbitt		*							
	Regale					+			*	
	Roanoke					+				
	Scuppernong			+		*				
	Sterling				*	*				
	Tarheel					+				*
	Triumph		*					*		
	Watergate				+					
	Welder		*							

[z]Information based on responses of muscadine researchers and extension specialists surveyed in each state. Group indicates approximate overall cultivar importance. Cultivar importance in each state is estimated as primary (*) or secondary (+).

Table 3. Characteristics and primary uses of important or well-known muscadine cultivars.

Cultivar	Average vine vigor	Flower type[z]	Fruit color[y]	Berry size[x]	Average yield	Harvest period[w]	Primary use[v] Wine	Juice	Process	Fresh, U-pick
Carlos	High	Per	Brz	Med	High	Early	*	*	+	*
Cowart	Med	Per	Blk	Lrg	Med	Mid				*
Doreen	VHigh	Per	Brz	Small	High	Late	*	*	*	
Fry	Low	Fem	Brz	Lrg	High	M-L				*
Higgins	Med	Fem	Brz	Lrg	High	Mid				*
Hunt	VHigh	Fem	Blk	Med	Med	Early	*			
Jumbo	Med	Fem	Pur	VLrg	VHigh	Mid			*	*
Magnolia	Med	Per	Brz	Med	High	Mid	*	*	*	
Noble	High	Per	Blk	Small	High	Early	*		*	*
Scúpper-nong	High	Fem	Brz	Med	Low	Mid	+	+	+	
Sterling	Med	Per	Brz	Med	High	Mid	+	*	+	
Sugargate	Med	Fem	Pur	VLrg	Low	Early				*
Summit	High	Fem	Brz	Lrg	High	Mid		+	+	*
Tarheel	High	Per	Blk	Small	High	Mid	*	*	*	
Watergate	Med	Fem	Brz	VLrg	High	Mid				*

[z]Flower type is perfect (Per) or female (Fern).
[y]Fruit color is bronze (Brz), purple (Pur), or black (Blk).
[x]Fruit size is based on average berry fresh weight: Small (2.1 to 4.0 g), Med (4.1 to 6.0 g), Lrg (6.1 to 8.0 g), VLrg (8.1 to 10.0 g) .
[w]Harvest period is Early (25 Aug.-9 Sept.), Mid-season (10-24 Sept.), or Late (25 Sept.-5 Oct.).
[v]Use is categorized as primary (*) or secondary (+).

Table 4. Problems and strengths of the muscadine industry.

Problem	Strength
Environmental	
Cold injury in northern range of production.	Relatively drought-tolerant.
Poor tolerance to wet or heavy soil.	
Mg deficiency common.	
Pests, diseases	
Fruit rots.	Broad tolerance to diseases and pests compared to *Euvitis* grapes.
Grape root borer.	
Physiological, cultural, genetic	
Uneven fruit ripening.	Will survive neglect, long life in good sites.
"Wet stem scar", rapid fruit decay.	Potential for very high yields with good management and cultivar choice.
Poor fruit set due to "cap sticking" as flowers open, especially 'Sugargate' and 'Fry'.	Improved cultivars are being developed, seedless cultivars may be possible.
Excessive shoot growth/fruit load.	Improved methods for wine and processed products developed for flavor and color stability.
Poor plant establishment and early growth.	
Low yields due to poor cultivars, site, or vineyard management.	
Economic	
Unstable markets.	Good current market diversity in fresh market, wine, juice, and processing industries.
Low prices paid by processors.	Incentive programs have been established by states to help finance costs of vineyard establishment.
Poor consumer familiarity with muscadines outside of the southeastern United States.	
Large initial investment.	
Significant yield not obtained until 3 to 5 years after planting.	

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