

‘Mountain Vineyard’ Hybrid Grape Tomato and Its Parents: NC 4 Grape and NC 5 Grape Tomato Breeding Lines

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‘Mountain Vineyard’ is a hybrid grape tomato (*Solanum lycopersicum* L.) resulting from the cross of NC 4 grape × NC 5 grape. It has a compact, indeterminate growth habit with short internodes conferred by the brachytic gene (*br*). It is heterozygous for the *I-3* gene for resistance to fusarium wilt race 3 [*Fusarium oxysporum* f.sp. *lycopersici* (Sacc.) Snyd. and Hans.] and the *Sw-5* gene for resistance to *Tomato spotted wilt virus* (TSWV). Fruits are high in soluble solids with an attractive deep red color resulting from the recessive crimson gene (*Bc* or *og^c*) in homozygous condition.

Origin

‘Mountain Vineyard’ (tested as NC 10235) is the culmination of a tomato breeding effort initiated in 2002 to develop a superior hybrid grape tomato comparable to the highly successful ‘Smarty’ hybrid (NC 3 grape × NC 2 grape) in horticultural traits with improved fruit color resulting from the crimson (*Bc* or *og^c*) gene combined with fusarium wilt race 3 and TSWV resistances.

NC 4 grape shares the *Sw-5* gene for TSWV and the *I-3* gene for fusarium wilt race 3 resistances, which were derived from the large, round-fruited hybrid ‘Amelia’ codeveloped by North Carolina State University and Clause Seed Co. A cross was made in the greenhouse in Fall 2002 between an F₄ generation inbred line homozygous for *Sw-5* and *I-3* developed by selfing ‘Amelia’ (Fig. 1) and the plum tomato breeding line NC EBR-7 (Gardner, 2006). This F₁ hybrid, 034, was selfed to produce a plum tomato line, 034 (x)-69-1, which is homozygous for *Sw-5* and *I-3* as determined by molecular markers closely linked to the two genes. The 034 selfed line

was crossed to NC 2 grape (Gardner and Panthee, 2010a) to develop the F₁ hybrid 0579, which was selfed to develop the F₄ generation inbred line, 0579 (x)-43-7-4, a large

grape-type tomato with a compact indeterminate growth habit and short internodes resulting from the *br* gene derived from NC 2 Grape (Gardner and Panthee, 2010a). The 0579 line tested homozygous-resistant for *Sw-5* and *I-3* using molecular marker-assisted selection.

The determinate (*sp* gene) grape tomato line NC 3 grape (Gardner and Panthee, 2010a) was used as the source of the crimson gene (*og^c*) and the *ms-10* male sterile gene linked to the anthocyanin absent (*aa*) seedling marker gene in NC 4 grape (Fig. 1). A crimson, *ms-10aa* determinate F₃ selection [032 (x)-5-11 gsms] from the cross of NC 3 grape with another determinate, crimson grape tomato line, was crossed to NC 2 grape, and 2000 plants from the F₂ generation of this cross (042) were grown to flowering in the greenhouse. A large F₂ population was needed to break the very tight linkage, reported as one crossover unit of the *og^c* (or *Bc*) gene to the *sp* gene for determinate growth habit (Mutschler et al., 1987). The recessive crimson

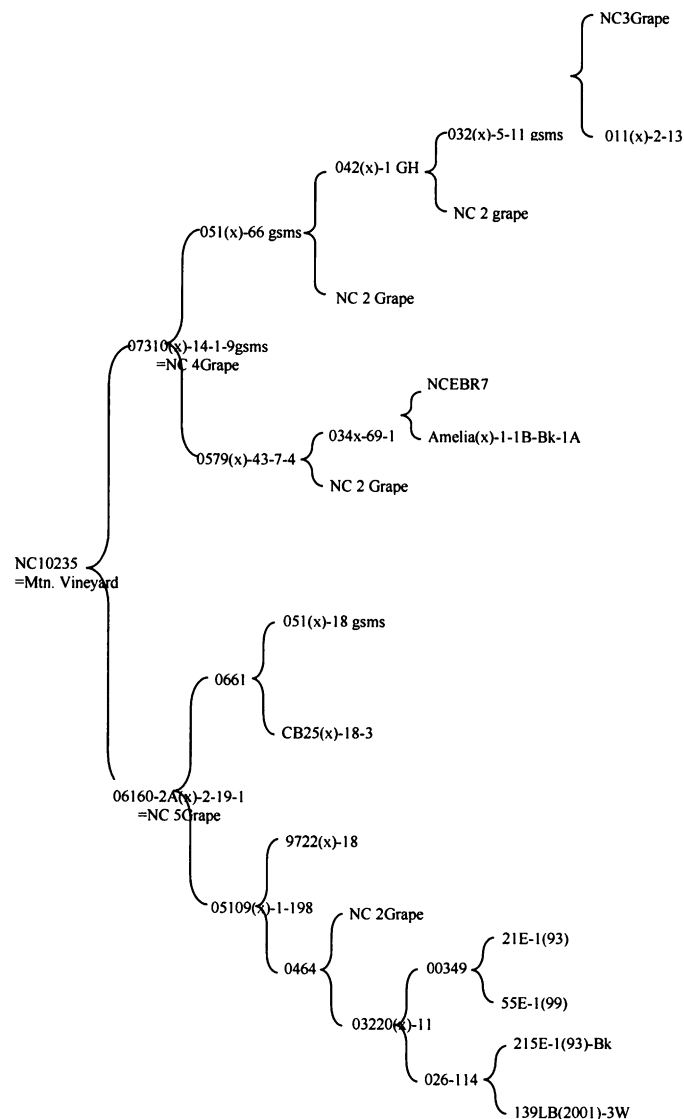


Fig. 1. Pedigree of ‘Mountain Vineyard’ hybrid grape tomato and its parents, NC 4 grape and NC 5 grape tomato breeding lines.

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gene segregates in the F₂ population (≈500 plants) were saved based on the distinctive dark, golden yellow stripes on the flower petals when *og^c* is present in a homozygous condition. Plants with the *og^c* flower color were grown until determination could be made for indeterminate vs. determinate growth habit by number of leaves between flower clusters, three for indeterminate and less than three for determinate. The indeterminate, crimson F₂ selection 042 (x)-1GH was crossed to NC 2 grape, and an F₂ selection from this cross, 051 (x)-66gsms, that was homozygous for the *og^c* gene linked to indeterminate growth and carrying the *ms-10,aa* gene combination was used in further crossing.

The cross of 051 (x)-66 gsms × 0579 (x)-43-7-4 produced the F₁ hybrid 07310. A population of 192 plants in the F₂ generation of 07310 was grown in the greenhouse and selected for desirable plant and fruit traits. The subsequent F₃ brachytic, indeterminate selection 07310(x)-14-1, outstanding in plant and fruit type, was homozygous for *og^c*, heterozygous for the *ms-10, aa* combination, and homozygous for both *Sw-5* and *I-3* as determined by molecular markers tightly linked to the two disease resistance genes. The F₄ selection 07310(x)-14-1-9 was made from the field in 2009 based on desirable horticultural traits. It segregated for the *ms-10, aa* gene combination and homozygous for *og^c* and continued to test homozygous for *Sw-5* and *I-3* genes according to tightly linked molecular markers (Fig. 2). Seed of this F₄ selection were bulked in F₅ selfed generation, and it is being released as NC 4 grape.

NC 5 grape shares some of the same pedigree as NC 4 grape up to the 051 hybrid (Fig. 1). An F₂ selection from this cross, 051 (x)-18 gsms, that was homozygous for the *og^c* gene linked to indeterminate growth was crossed to CB 25 (x)-18-3, an F₃ indeterminate, brachytic, high sugar tomato line resulting from selfing the CB 25 (F₁ hybrid of a Clause proprietary cherry tomato line × NC 1 grape) to produce the 0661 F₁ hybrid.

For the pedigree leading to NC 5 grape, NC 2 grape was crossed in the greenhouse in the fall of 2003 to the large, round-fruited early blight/late blight-resistant line 03220 (x)-11 to produce the F₁ hybrid 0464. The 03220 hybrid was also selfed to develop the early blight/late blight-resistant breeding lines NC 1CELBR and NC 2CELBR (Gardner and Panthee, 2010b). The 0464 hybrid was then crossed with 9722 (x)-18, an early blight/late blight-resistant F₂ cherry tomato selection derived from backcrossing the *Ph-3* gene for late blight resistance from the *S. pimpinellifolium* L 3707 selection into the early blight-resistant line 215E-1 (93). The resultant F₁ hybrid, 05109, was selfed, grown in the field in the F₂ generation, and selected for late blight resistance and horticultural traits. The F₃ generation line was then grown in the greenhouse, and 05109 (x)-1-198, a high sugar cherry tomato selection, was identified as late blight-resistant by a detached leaf inoculation technique.

NC0661 was crossed with 05109(x)-1-198 to produce the F₁ hybrid 06160. A single F₁ plant selection from this cross, 06160-2A, was selfed, and the F₂ generation was grown in the field in 2007 to produce the outstanding crimson, compact indeterminate, brachytic grape tomato selection 06160-2A(x)-2. Subsequent selfing and selection in the greenhouse and field led to the F₄ generation line 06160-2A(x)-2-19-1, of which seed were bulked in selfed generations beyond the F₄ for release as NC 5 grape.

Description

‘Mountain Vineyard’ is the first known indeterminate grape tomato hybrid with the homozygous recessive crimson (*og^c*) gene for improved red fruit color and increased lycopene content. It has short internodes conferred by the brachytic (*br*) gene. Foliage is dark green in color and provides good cover for the fruit. Immature fruits have a glossy finish with dark green shoulders. Fruit of ‘Mountain

Vineyard’ develop a deep red color resulting from the crimson gene and are firm in the fully ripened stage. Fruit pedicels are jointed (*J2* gene), and the fruit separate easily from the pedicels during harvest. The fruit are long and ovate in shape and have good resistance to fruit cracking and bursting.

Yield and quality of ‘Mountain Vineyard’ was compared with ‘Smarty’, a hybrid with very similar plant and fruit type. When averaged over four field trials with three replications each conducted during the summer seasons of 2010–12, ‘Mountain Vineyard’ was lower than ‘Smarty’ for total and marketable yields and percent soluble solids. However, marketable yield (%) of ‘Mountain Vineyard’ was significantly higher than ‘Smarty’ (Table 1). Average fruit size did not differ for the two cultivars.

‘Mountain Vineyard’ has received good taste test reviews and grown well in numerous observational trials in research station and growers’ fields in western North Carolina and the coastal area of South Carolina. Flavor

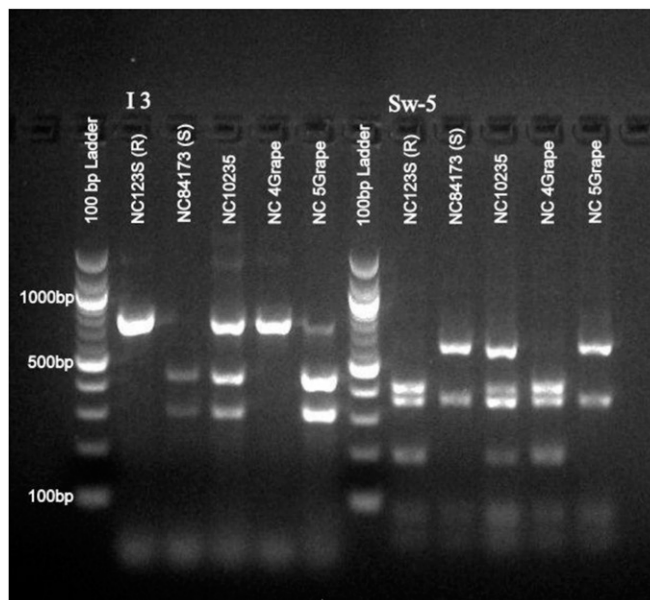


Fig. 2. Molecular markers analysis for fusarium wilt race 3 resistance conferred by *I-3* gene (left panel) and *Tomato spotted wilt virus* resistance conferred by *Sw-5* gene (right panel separated by DNA ladder) in NC10235 (‘Mountain Vineyard’), NC 4 grape, and NC 5 grape breeding lines. NC 123S and NC 84173 were used as resistant and susceptible controls, respectively. Molecular markers associated with *I-3* (TG217) and *Sw-5* (NCSw-011) are cleaved amplified polymorphic sequence (CAPS) type (Panthee and Ibrahim, 2013).

Table 1. Average yield, fruit size, and total soluble solids of NC 5 grape tomato and the F₁ hybrid ‘Mountain Vineyard’ (NC 4 grape × NC 5 grape) compared with the control F₁ hybrid grape tomato ‘Smarty’.^z

Genotype	Total yield (t·ha ⁻¹)	Marketable yield (t·ha ⁻¹)	Marketable (%)	Fruit wt (g)	Total soluble solids (%) ^y
Mountain Vineyard	38.3	36.5	94.4	10.0	6.8
Smarty	43.7	41.0	91.7	9.8	7.5
NC 5 grape	40.1	38.0	94.8	9.3	7.1
LSD(0.05)	3.4	3.4	1.2	1.6	0.4

^zData are the average of early and late replicated trials in 2010, an early trial in 2011, and late trial in 2012 with three replicates each at the Mountain Horticultural Crops Research and Extension Center, Mills River, NC. Least square means (LSMeans) and least significant difference (LSD) values presented in the table were obtained from analysis of variance performed using SAS software (SAS Institute Inc., 2007).

^yTSS was measured only in 2010 and 2011.

and fruit texture of 'Mountain Vineyard' have been rated excellent in subjective taste evaluations in research station plots by growers and consumers. Despite somewhat lower yields and lower percent soluble solids than 'Smarty', 'Mountain Vineyard' was consistently rated as highly promising in research station and grower trials because of its combination of desirable horticultural traits and disease resistances. In grower trials in coastal South Carolina, 'Mountain Vineyard' was free of TSWV symptoms, whereas 'Smarty' was severely affected. Presence of the *Sw-5* gene for TSWV resistance (Panthee and Ibrahim, 2013) and the *I-3* gene for fusarium wilt race 3 resistance (Barillas et al., 2008) in heterozygous condition was verified by a molecular markers tightly linked to the resistance genes (Fig. 2). In a seedling inoculation trial in a growth chamber, 'Mountain Vineyard' was resistant to fusarium wilt race 3.

NC 4 grape is a unique tomato breeding line with a desirable combination of disease resistance genes and horticultural traits. It has a compact, indeterminate growth habit with short internodes conditioned by the *br* gene and has heavy dark green foliage cover for fruit protection. Fruit average weighs ≈ 10 g. The fruit are a desirable elongate grape tomato shape, develop a deep red interior color as a result of the crimson gene, are crisp in texture with a sweet flavor, and are firm in the fully ripened stage. Ripe fruit have good resistance to bursting and cracking. Immature fruit have a glossy, uniform light green color (*u* gene). Fruit pedicels are jointless, and the fruit separate easily from the pedicels at harvest. NC 4 grape is heterozygous for the *ms-10* male-sterile gene linked to the green stem seedling marker gene *aa*. This allows for selection of male-sterile plants at the seedling stage for use of NC 4 grape as a female parent for making F₁ hybrids without the need to emasculate flowers or being concerned about self-pollination of the female parent when making crosses. In addition, stigmas are well exerted on male-sterile flowers of NC 4 grape so they are easily accessible for pollen application. NC 4 grape has the *Sw-5* and *I-3* genes for resistance to TSWV and fusarium wilt race 3, respectively.

The NC 5 grape tomato breeding line has a vigorous plant with a compact indeterminate growth habit with short internodes conferred by the *br* gene. Foliage is an attractive dark green color, providing good coverage for fruit protection and holding up well throughout the season. Immature fruits have a glossy finish with a dark green shoulder color. Fruit pedicels are jointless, and the fruit separate easily from the pedicels at harvest. Fruit of NC 5 grape tomato average ≈ 10 g and have an ideal elongate shape desired for grape tomatoes. The crimson (*og^c*) fruit develop a deep, attractive red color, are crisp in texture with a sweet flavor, and are firm in the fully ripened stage. Fruit maintain good quality on the plant for an extended period after ripening without bursting or cracking. NC 5 grape was susceptible to late blight in a replicated greenhouse disease screen in 2012. NC 4 grape and NC 5 grape have not been tested for other disease resistance genes. However, based on resistances present in parent lines leading to their development, both lines have the potential to have the *Ve* gene for resistance to verticillium wilt and the *I* gene for resistance to race 1 of fusarium wilt. These lines were not found to have *I-2* gene conferring resistance to race 2 of fusarium wilt (data not shown).

NC 5 grape was compared in replicated yield trials with 'Smarty'. When averaged over four trials with three replications each at Mountain Horticultural Crops Research Station (MHCRS), NC 5 grape was slightly lower in total yield and total soluble solids, the same in marketable yield and fruit size, and significantly higher in percent marketable grade fruit than 'Smarty' (Table 1).

Use

'Mountain Vineyard' provides growers in North Carolina and other regions with similar growing conditions a high-yielding, fusarium wilt race 3 and TSWV-resistant grape tomato cultivar with improved fruit color, desirable plant growth habit, and other fruit traits comparable to 'Smarty'. The NC 4 grape and NC 5 grape, both of which have the *og^c* gene linked to indeterminate growth habit, provide tomato breeders with superior fruit quality and yield

potential, which should be useful in breeding and as parents in other F₁ hybrids. NC 4 grape should be especially useful because of its combination of the *Sw-5*, *I-3*, *br*, *ms-10*, *aa*, *og^c*, and *j2* genes in a breeding line highly adapted for use as a female parent in developing grape tomato hybrids.

Availability

'Mountain Vineyard' will be licensed to a private seed company on an exclusive basis for seed production and sales. It is expected that commercial seed will be available in 2015. Distribution of seed of NC 4 grape and NC 5 grape to other breeders requires a signed material transfer agreement that can be downloaded at the following web site address: <<http://www.ces.ncsu.edu/fletcher/programs/tomato/releases/tomato-seed-production-and-license-agreement.pdf>>. Small trial samples of 'Mountain Vineyard' are available from D.R. Panthee (dilip_panthee@ncsu.edu), MHCRC, 455 Research Drive, Mills River, NC 28759.

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