Apple rootstocks can modulate the chilling requirements of grafted scions

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Abstract

Apple rootstocks modify scions at the molecular level modulating gene expression and hormone flux. Some Geneva® apple rootstocks show increased productivity in low chill environments by causing more floral and vegetative buds to break in the top 1/3 of high chill scions like Gala (~890) and Fuji (~1150). We used an existing, mature (8th leaf) 'Gala' orchard featuring a full-sib population of rootstocks. To measure the effect of rootstocks on bud break we harvested 30 cm one-year growth shoots for replicated experiments in 2 consecutive years (2017-2018). In 2017 shoots were harvested when the trees had accumulated 800 hours (North Carolina model) of chilling were then placed directly into a greenhouse environment (20° C day/17° C night). In 2018 we tested three chilling hour accumulation levels (585 hours, 702 hours and 906 hours). In 2018 shoots were harvested on November 22 when the trees had accumulated 585 chill hours and a set was placed directly in the greenhouse at 20° C day/17° C night while the rest were stored at 5° C until they had reached the desired chilling hour accumulation (702h and 906h) to be placed in the same greenhouse environment. Bud break was recorded at 15 and 30 days after move in greenhouse. Rootstock genotype and chilling treatment had a significant effect on apical and lateral bud opening in both years. Normally, apical buds opened first, followed by laterals. In 2017 approximately 50% of the rootstock genotypes had one or more buds open after 30 days indicating a significant rootstock effect on the scion chilling requirement. In 2018 the proportion of rootstock genotypes displaying open buds after 30 days increased with increasing chilling hours (585h=10%; 706h=20%; 906h=38%). These preliminary results in the germplasm tested, show a definite genetic effect by apple rootstocks on scion chilling requirement.

Keywords: endo-dormancy, rootstock, breeding, eco-dormancy, bud break.

INTRODUCTION

One of the effects of climate change on apple production is to reduce apple growing areas where winter temperatures fail to dip below 7C for extended periods in order to satisfy the winter chill requirement of apples (Midgley and Lotze, 2011; Bergamaschi et al., 2012; Cardoso et al., 2012). Lack of chilling happens in some apple-growing regions of the world where apple trees experience too little winter cold to satisfy the endodormancy (chilling) requirement specific to each scion variety (Cook and Jacobs, 1999; Rufato et al., 2010). Different models have been developed to describe scion cultivar-specific chilling requirements (Anzanello et al., 2014; Asakura, 2011; Guak and Neilsen, 2013; Neilsen et al., 2015; Pola et al., 1994). In the spring, apple trees that do not achieve adequate chilling, display a low percentage and/or delay of bud burst (especially in the top 1/3 of the tree), with a high percentage of buds failing to grow and subsequently dying (Macedo et al., 2018a; Macedo et al., 2018b; Rufato et al., 2010). The number of flowers that can be converted into fruit and timing of opening of those flowers are also affected resulting in losses between 15-45% in production (Macedo et al. 2019). Apple rootstocks have been shown to affect bud break in scions that have experienced insufficient chilling (Couvillon et al. 1984; Young and Werner, 1984; Young and Werner, 1984; Young and Werner, 1985).

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Recently, researchers in Brazil found that Geneva 213 rootstock had a greater percentage of buds that grew in the spring after mild winters compared to 'M.9' or 'Marubakaido' rootstocks and interstems (Macedo et al., 2018a). This and other Geneva® rootstocks that may possess chilling requirement reducing properties ('G.210' and 'G.814') belong to the same full-sib family resulting from the cross between 'Ottawa 3' and 'Robusta 5' (Bartish et al., 1999). Phytohormone content in scion cultivars has been shown to be modulated by genetically different rootstocks which may also influence specific endodormancy requirements at the onset of dormancy in the fall (van Hooijdonk et al., 2011; Tworkoski and Fazio, 2016; Adams et al., 2018). This set of experiments was designed to validate observations of Geneva rootstocks behavior observed in low chill environments and gain genetic insights for this trait by testing full-sib populations of those rootstocks in Geneva, NY.

MATERIALS AND METHODS

We used an existing, mature (8th leaf) orchard featuring a full-sib population of rootstocks derived from the cross between 'Ottawa 3' and 'Robusta 5' that had been grafted with 'Gala' scion. For all experiments, we harvested 30 cm one-year growth shoots for a replicated experiment to measure the effect of rootstocks on bud break.

In 2017 we tested one level of chilling hour accumulation (800 hours) measured according to the North Carolina model to see if we could observe the phenomenon in Geneva, NY. Shoots were harvested when the trees had accumulated 800 hours of chilling and were then stuck in floral foam in a completely randomized design and placed in water-filled trays. Trays were placed directly into a greenhouse environment (20° C day/17° C night). We counted the number of buds open per bud stick and generated genotype means.

Figure 1. Experimental setup of completely randomized bud sticks harvested from 'Gala' scions grafted onto 127 apple rootstocks belonging to the breeding family 'Ottawa 3' x 'Robusta 5'.

In 2018 we tested three chilling hour accumulation levels (Treatment 1: 585 hours, Treatment 2: 702 hours, Treatment 3: 906 hours). Shoots were harvested on November 22 when the trees had accumulated 585 chill hours. All shoots were stuck in floral foam in a completely randomized design with water reaching the cut areas. Shoots in treatment 1 were placed in the greenhouse at 20° C day/17° C night while shoots from treatment 2 and treatment 3 were stored at 5° C until they had reached the desired chilling hour accumulation and then were placed in the same greenhouse environment for pushing. Bud sticks that had no open buds were given a value of 0 whereas bud sticks that had one or more buds open were given a value of 1.

For all treatments/years, bud break was recorded 30 days after the introduction on the greenhouse. Statistical analyses and graphs were obtained with SAS JMP15-Pro software (Cary, NC 27513-2414, USA).

Figure 2. Examples of bud break recorded after 30 days that show replicate uniformity.

RESULTS AND DISCUSSION

Rootstock genotype and chilling treatment had a significant effect on apical and lateral bud opening in both years. Apical buds opened first and were followed by laterals. In 2017 approximately 50% of the rootstock genotypes had one or more buds open after 30 days indicating a significant rootstock effect on the scion chilling requirement. In 2018 the proportion of rootstock genotypes displaying open buds after 30 days increased with increasing chilling hours (585h=10%; 706h=20%; 906h=38%) perhaps indicating a quantitative trait effect.

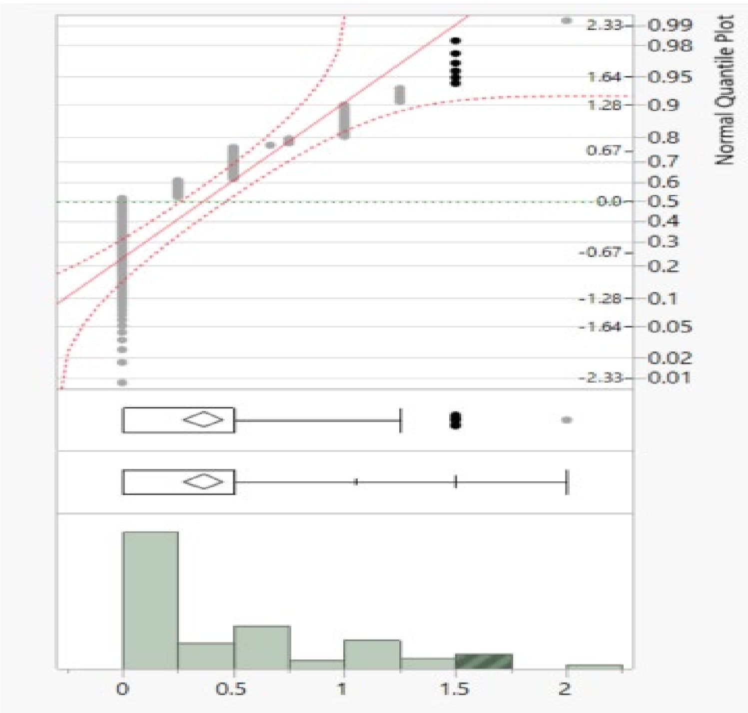

Figure 3. Genotypic mean total number of buds open per Gala scion bud stick that were grafted onto 116 different rootstock genotypes.

These sets of experiments were conducted to learn more about the repeatability of observations made in Brazil that involved rootstocks ('G.213' and 'G.814') related (full sibs) to the breeding population in this work. Early reports in the 1970s indicated that in the Malling series there were differential effects of rootstocks on scion chilling requirements where 'M.7' lowered the chilling requirement of grafted scions compared to 'M.9' (Couvillon et al., 1984a; Young and Werner, 1984b). Current dogma on chilling hour accumulation does not include any root influenced component, which is clearly disproven by these sets of experiments. Several root influenced factors including phytohormone content, global gene expression, nutrient content, and metabolite content have been described in the past 15 years (Jensen et al., 2010; Tworkoski and Fazio, 2016; Adams et al., 2018). Related traits (sylleptic bud break in the nursery) have also been reported for related apple rootstocks (Fazio and Robinson, 2008; Rufato et al., 2019). It is likely that one of the molecular components that make up the endodormancy system may be influenced by a gradient modulated by rootstock genotype. Genotypic mean distributions are often used to deduce the complexity of a trait. In this case, we see a very small percentage of rootstocks in the population possessing a very strong ability to reduce chill hour requirement in the scion, perhaps indicating a complex genetic inheritance (three or more loci).

The chilling requirement is related to endodormancy while the ability of buds to open when placed in a warm environment is related to ecodormancy (accumulation of heat units). The number of buds open after 30 days is interpreted as a genotype effect on endodormancy while rootstock effects on ecodormancy could be interpreted as the differences in the proportion of open bud genotypes between the first and second observation times in the greenhouse (not reported here). Although these are preliminary results, they show that in the germplasm tested, there is a definite effect of apple rootstock on scion chilling requirement and perhaps ecodormancy.

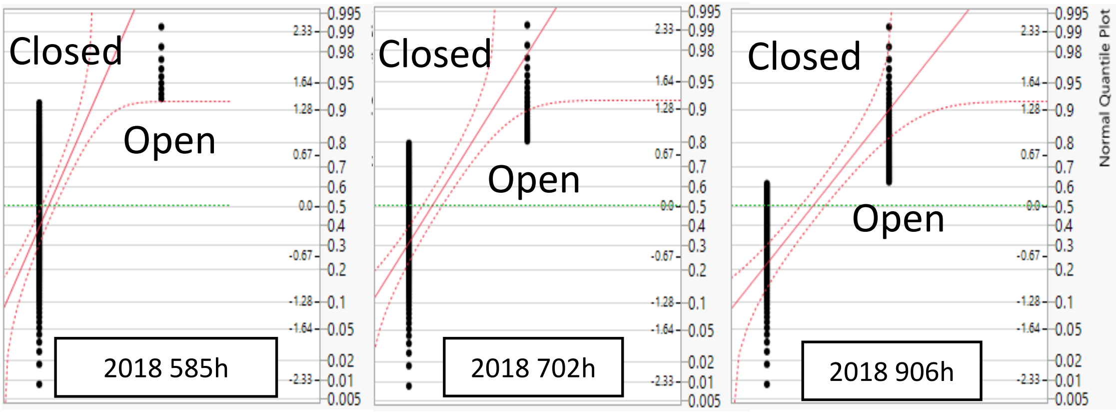

Figure 4. Genotypic mean distribution of rootstock genotype induced Gala scion buds open by chilling treatment (585h, 706h, 906h) and 30 days in greenhouse.

CONCLUSIONS

Regardless of physiological and genetic underpinnings for this rootstock-influenced trait, in a low chill environment, it does increase the productivity of the orchard by 15-45% depending on the severity of the lack of chill and the sensitivity of the scion variety. This rootstock effect has repercussions in apple production areas threatened by loss of chilling due to climate change that are in borderline regions where winters are becoming milder. It remains to be seen if this rootstock trait has any incidence on the eco-dormancy requirement of scions or mid-winter hardiness. So far, rootstocks possessing this trait have survived at least 45 Geneva, New York winters with and without scions.

ACKNOWLEGMENTS

We would like to thank technicians Abby Nedrow, Jessica Fisk, Sarah Bauer and Todd Holleran for collecting plant material, setting up the experiments and collecting data. The projects described in this manuscript were also partially funded by the USDA NIFA SCRI CRIS PROJ NO: NYC-145543 "Accelerating the development, evaluation, and adoption of new apple rootstock technologies to improve apple growers' profitability and sustainability". The contents of this publication do not necessarily reflect the views or policies of the US Department of Agriculture, nor does mention of trade names, commercial products, or organizations imply endorsement by the US Government.

Literature cited

Adams, S., Lordan, J., Fazio, G., Bugbee, B., Francescatto, P., Robinson, T.L., and Black B. (2018). Effect of scion and graft type on transpiration, hydraulic resistance and xylem hormone profile of apples grafted on Geneva® 41 and M.9-NIC (TM) 29 rootstocks. Scientia Horticulturae *227*:213-222.

Anzanello, R., Fialho, F.B., dos Santos, H.P., Bergamaschi, H. and Marodin, G.A.B. (2014). Bud dormancy in apple trees after thermal fluctuations. Pesquisa Agropecuaria Brasileira *49*:457-464.

Asakura, T. (2011). Model prediction of the spring phenology for 'Fuji' apple. Acta Hort. *903*:1135-1140.

Bartish, I.V., Weeden, N.F., Tobutt, K.R. and Alston, F.H. (1999). The use of interspecific crosses in Malus to map the genes of characters important for apple rootstock breeding. Acta Hort. *484*:319-323.

Cardoso, L.S., Bergamaschi, H., Bosco, L.C., de Paula, V.A., Marodin, G.A.B., Casamali, B. and Nachtigall, G.R. (2012). Climate availability for apple trees in Vacaria, southern Brazil. Ciencia Rural *42*:1960-1967.

Cook, N.C. and Jacobs, G. (1999). Suboptimal winter chilling impedes development of acrotony in apple shoots. HortScience *34*:1213-1216.

Couvillon, G.A., Finardi, N., Magnani, M. and Freire, C. (1984). Rootstock influences the chilling requirement of 'Rome Beauty' apple in Brazil. HortScience *19*:255-256.

Fazio, G. and Robinson, T.L. (2008). Modification of Nursery Tree Architecture with Apple Rootstocks: A Breeding Perspective. New York Fruit Quarterly *16*:13-16.

Guak, S. and Neilsen, D. (2013). Chill unit models for predicting dormancy completion of floral buds in apple and sweet cherry. Hortic Environ Biote *54*:29-36.

Jensen, P.J., Makalowska, I., Altman, N., Fazio, G., Praul, C., Maximova, S.N., Crassweller, R.M., Travis, J.W. and McNellis, T.W. (2010). Rootstock-regulated gene expression patterns in apple tree scions. Tree Genetics & Genomes *6*:57-72.

Macedo, T.A., Sander, G.F., Michelon, M.F., Carminatti, J.F., Rufato, A.R., Rufato, L. and Robinson, T.L. (2018a). Chilling requirement and budburst uniformity of cultivar 'Maxi Gala' grafted on different rootstocks. Acta Hort. *1228*:241-245.

Macedo, T.A., Sander, G.F., Rufato, A.R., Rufato, L., Kretzschmar, A.A. and Magro, M. (2018b). Development and productivity of 'Maxi Gala' apple trees at different planting depths. Acta Hort. *1228*:113-116.

Macedo, T.A.d., Silva, P.S.d., Sander, G.F., Welter, J.F., Rufato, L. and Rossi, A.d. (2019). Productivity and quality of "Fuji Suprema" apple fruit in different rootstocks and growing conditions. Scientia Horticulturae *256*:108651-108651.

Midgley, S.J.E. and Lotze, E. (2011). Climate change in the Western Cape of South Africa: trends, projections and implications for chill unit accumulation. Acta Hort. *903*:1127-1134.

Neilsen, D., Losso, I., Neilsen, G. and Guak, S. (2015). Development of Chilling and Forcing Relationships for Modeling Spring Phenology of Apple and Sweet Cherry. Acta Hort. *1068*:125-132.

Pola, A.C., Bleicher, J. and Bernardi, J. (1994). Predicting bud burst in the apple cultivar Gala. Agropecuaria Catarinense *7*:24-28.

Rufato, L., Kretzschmar, A.A., Brighenti, A.F., Macedo, T.A., Mendes, M. and Silva, L.C. 2010. Bud Break in Different Cultivars of Apple Trees in Two Regions of Santa Catarina State, Brazil. Acta Hort. *884*:643-646.

Rufato, L., Marchioretto, L.D.R., Orlandi, J.C., Michelon, M.F., De Rossi, A., Sander, G.F. and de Macedo, T.A. (2019). Lateral branch induction at nursery with growth regulators in 'maxi gala' apple trees grafted on four rootstocks. Scientia Horticulturae *253*:349-357.

Tworkoski, T. and Fazio, G. (2016). Hormone and growth interactions of scions and size-controlling rootstocks of young apple trees. Plant Growth Regulation *78*:105-119.

van Hooijdonk, B., Woolley, D., Warrington, I. and Tustin, S. (2011). Rootstocks Modify Scion Architecture, Endogenous Hormones, and Root Growth of Newly Grafted 'Royal Gala' Apple Trees. Journal of the American Society for Horticultural Science *136*:93-102.

Young, E. and Werner, D.J. (1984a). Effects of rootstock and scion chilling during rest on resumption of growth in apple and peach. Journal of the American Society for Horticultural Science *109*:548-551.

Young, E. and Werner, D.J. (1984b). Rootstock and scion chilling effects on apple and peach bud break. Compact Fruit Tree *17*:32-36.

Young, E. and Werner, D.J. (1985). Effects of shoot, root, and shank chilling during rest in apple and peach on growth resumption and carbohydrates. Journal of the American Society for Horticultural Science *110*:769-774.