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Rootstock Effects on Flower Bud Mortality in 'Gala' and 'Fuji' Apples Under Natural Spring Frost Conditions (2021–2023)

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Introduction

Spring frost is among the most economically damaging weather events in apple production, often causing substantial losses during critical stages of flower bud development (Saini et al., 2025). The temperature threshold for frost injury varies depending on multiple factors, including species, bud developmental stage, and duration of exposure. Buds in early dormancy tend to be more cold-hardy than those in later stages (North and Kovaleski, 2023). For example, silver tip buds in apple can tolerate temperatures as low as 3 °F, whereas post-bloom buds may suffer near-total loss at temperatures around 25 °F (Michigan State University Extension, 2021; Figure 1). Ultimately, both the severity and duration of cold exposure determine the extent of damage — the colder and longer the event, the greater the injury.

In deciduous fruit trees, buds survive winter cold by hardening off — a seasonal adaptation process driven by changes in day length and temperature. In autumn, shorter days and cool nights trigger cold acclimation: growth slows, cell walls strengthen, and buds accumulate natural 'antifreeze' compounds such as simple sugars, potassium, proline, and specialized antifreeze proteins (Hummel and Ophardt, 2016; Jahed et al., 2023). These cryoprotectants help stabilize membranes, limit ice crystal formation, and slightly depress the freezing point of cellular fluids (Ambroise et al., 2020). With prolonged exposure to subfreezing temperatures, buds reach midwinter hardiness; in some *Malus* species, they can tolerate temperatures approaching –40 °F (Yushkov et al., 2020). However, as late winter warmth returns, buds begin to deacclimate: protective solutes are diluted, and membranes lose their resilience (Rys et al., 2020). A sudden cold snap at this stage can cause intracellular ice formation or draw water out of the cells, often resulting in bud death (Zhang et al., 2019).

Warming weather trends are being documented worldwide. In Winchester, Virginia, for example, the USDA Plant Hardiness Zone has shifted from 6b (–5°F to 0°F) to 7a (0°F to 5°F) over the past decade, reflecting a 5°F increase in average annual extreme minimum temperatures (Figure 2). This subtle but significant warming accelerates bud development and reduces the buffer between dormancy release and frost exposure — meaning that the same frost events now cause greater damage simply because they strike at more vulnerable developmental stages.

Rootstocks influence frost performance by affecting bloom timing, water relations, and overall tree vigor (Saini et al., 2025). While the exact defense mechanisms may vary by genotype, field observations indicate that apple cultivars grafted onto certain rootstocks consistently experience lower bud mortality after frost events. To provide Virginia growers with practical insights, we monitored natural frost events over three seasons (2021–2023) in Winchester and assessed flower bud mortality in 'Gala' and 'Fuji' apples grafted onto ten commercial rootstocks. The results below highlight the relative performance of each rootstock in preserving floral bud viability under these natural conditions. A detailed analysis of rootstock effects on scion cold tolerance was published in a peer-reviewed article by Saini et al. (2025).

Plant Material and Trial Characteristics

From 2021 through 2023, we evaluated natural spring frost injury in a research orchard at Virginia Tech's Alson H. Smith Jr. Agricultural Research and Extension Center (AREC) in Winchester, VA.

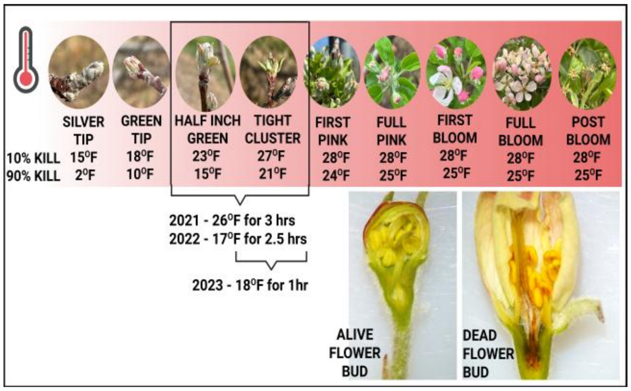

Figure 1. Critical spring temperatures for apple bud stages, with corresponding frost event conditions (temperature, duration, and stage) from 2021–2023. Cross-sections show live (left) and dead (right) flower buds.

The study was conducted on 12-year-old 'Gala' and 'Fuji' apple trees grafted on ten widely used rootstocks: B.9, M.26, G.935, G.11, G.16, G.30, G.41, MM.111, M.7, and M.9. These rootstocks represent several major breeding programs: B.9 belongs to the Budagovsky series developed in Russia; M.7, M.9, M.26, and MM.111 come from the historic Malling and Malling-Merton series in England; and the Geneva rootstocks (G.11, G.16, G.30, G.41, G.935) were developed in the U.S. through a collaboration between Cornell University and the USDA (Sherif, 2022). Trees were trained to a vertical axis system at 12 ft within-row and 22 ft between-row spacing and arranged in a randomized complete block design with four blocks. Each scion-rootstock combination was represented by two trees per block (total=8 trees per each rootstock-scion combination). Routine orchard care — including winter pruning, fertilization, and pest control — followed the recommendations in the Spray Bulletin for Commercial Tree Fruit Growers – (https://vtechworks.lib.vt.edu/handle/10919/84225).

An EasyLog® data logger placed within the experimental block recorded canopy air temperature every 10 minutes during each frost event. Using a combination of Weather Underground forecasts and logger data, we identified three frost events that occurred during apple bloom between 2021 and 2023: April 3, 2021; March 29, 2022; and March 20, 2023. For each event, 30 flower buds per scion–rootstock combination were collected six hours after the frost. King flowers (central blooms) were separated from side flowers, and all buds were bisected with a razor blade. Buds were scored as alive if the pistil appeared green and as dead if it was brown or black. Mortality was calculated using the following formula:

Bud mortality (%) = (Number of dead buds ÷ Total buds collected for that bud class [king or side]) × 100

King and side flowers were evaluated separately. Representative examples of live and frost-killed buds are shown in Figure 1.

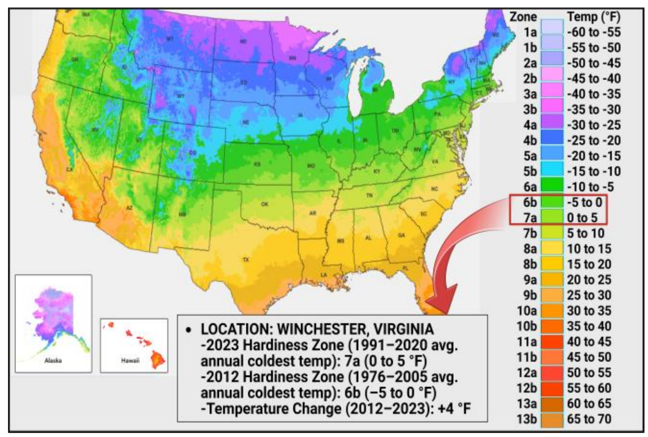

Figure 2. USDA Plant Hardiness Zone Map showing the shift in Winchester, Virginia from Zone 6b (-5 to 0 °F) to Zone 7a (0 to 5 °F) between 2012 and 2023. Source: U.S. Department of Agriculture (USDA).

Results

Figure 3 summarizes average bud mortality for 'Gala' (based on three years of data) and 'Fuji' (two years) apples grafted on ten rootstocks, based on three naturally occurring frost events from 2021–2023. Detailed year-specific results are reported in Saini et al., 2025, while a condensed summary is provided below.

In 2021, a damaging frost event was recorded on April 3, reaching 26.1 °F for 3 hours (Figure 1). At the time, both 'Fuji' and 'Gala' were in the half-inch green stage, a moderately sensitive phase in which green tissue is just emerging from the bud (Figure 1). Even though temperatures didn't meet the typical 90% kill thresholds, flower damage was still observed — likely influenced by reduced dewpoint.

For 'Fuji' king flowers, B.9 had the lowest observed mortality, but this was not statistically different from other rootstocks, including G.935, G.11, G.16, G.30, G.41 and MM.111. In contrast, M.26, M.9 and M.7 had the highest level of mortality, with losses significantly greater than those seen in B.9. In 'Fuji' side buds, B.9 again showed the lowest mortality, statistically lower than the highest-mortality group consisting of M.26 and G.30. The remaining rootstocks, including several Geneva and Malling types, had intermediate mortality, with no significant differences among them.

For 'Gala' king flowers, B.9 had the lowest mortality, significantly lower than MM.111, which recorded the highest damage. Most of the other rootstocks, such as M.26, M.9, G.935, and G.30, fell into an intermediate category and were not significantly different from either extreme. In 'Gala' side buds, B.9 had no mortality, whereas rootstocks like G.11 and G.16 had higher mortality rates. G.30, M.7, G.935 and M.26 showed moderate bud mortality.

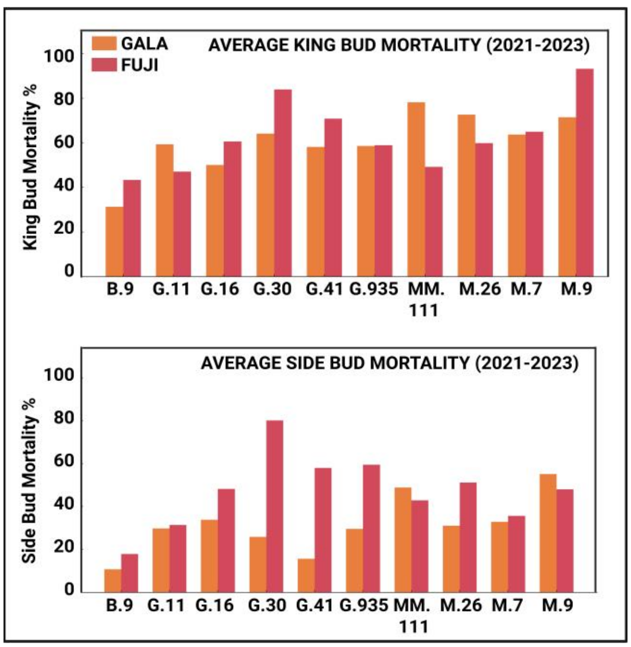

Figure 3. Average King and Side bud mortality (%) of 'Gala' and 'Fuji' apples grafted on ten different rootstocks across 2021–2023 spring frost seasons. Bars represent the mean of three seasons for 'Gala' and two seasons for 'Fuji'.

In 2022, a stronger frost occurred on March 29, when air temperature dropped to 17 °F for 2.5 hours (Figure 1). By this date, 'Fuji' trees were still in the half-inch green stage, while 'Gala' had progressed to tight cluster, a stage known to be especially vulnerable (Figure 1). This combination of low temperature and advanced bud development resulted in noticeable bud damage, particularly to king flowers.

In 'Fuji' king buds, M.9 and G.30 recorded the highest mortality, while B.9, G.935, G.11, G.16, M.7, M.111, and M.26 had lower bud mortality. For 'Fuji' side buds, no statistically significant differences were observed among rootstocks. However, B.9, G.11 and M.111 had slightly lower mortality rates than the rest.

In 'Gala' king buds, M.9, MM.111, M.26, and M.7 had the highest bud mortality, while B.9, G.935, and G.41 showed the lowest levels of damage and were significantly better than the most affected group. Other Geneva selections such as G.11, G.16, and G.30 fell in the intermediate range. For 'Gala' side buds, M.9 had the highest mortality, whereas B.9 and G.11 recorded the lowest. The other rootstocks—G.16, G.935, M.7, M.26, MM.111, G.30, and G.41 had intermediate bud mortality.

In 2023, the primary frost event took place on March 20, with a low of 18 °F for just over 1 hour (Figure 1). Bud stages again mirrored the previous year, with 'Fuji' in half-inch green and 'Gala' in tight cluster (Figure 1). Despite the shorter duration, the relatively advanced phenology in 'Gala' meant buds were less cold-hardy and more likely to be injured. In contrast, no visible damage was observed in 'Fuji' during this event, as the minimum temperature did not reach damaging thresholds for the half-inch green stage — thus, bud mortality data for 2023 were collected only from 'Gala'.

For 'Gala' king flowers, B.9 and G.16 demonstrated the lowest mortality. The highest mortality was observed in M.9, followed by elevated losses in M.26, G.41, and MM.111. Rootstocks like G.935, G.30, and M.7 showed moderate levels of damage, while G.11 fell somewhere in between, not significantly different from either the high or low mortality groups. In 'Gala' side buds, the Geneva rootstocks G.41, G.11, and G.16 had the lowest levels of mortality, performing significantly better than M.9 and MM.111, which had the highest side bud losses. Rootstocks such as B.9, G.935, G.30 and M.26 displayed moderate side bud mortality.

Summary and Conclusions

- From 2021 to 2023, we monitored natural spring frost events in 'Gala' and 'Fuji' apples grafted onto ten commercial rootstocks in Winchester, VA.
- Frost events occurred at critical developmental stages (half-inch green and tight cluster), with minimum temperatures ranging from 17 °F to 26 °F and durations between 30 minutes and 2.5 hours.
- King flowers were consistently more vulnerable to frost injury than side flowers, due to their earlier development.
- The B.9 rootstock showed consistently lower mortality for both king and side flowers across cultivars, indicating strong inherent frost resilience. In contrast, M.9 exhibited consistently higher bud mortality, while M.26 showed greater sensitivity in some seasons, particularly in 'Fuji' during 2021 and 'Gala' in 2023. Geneva rootstocks showed mixed performance: G.11 and G.41 generally had moderate to good bud survival, while G.30 and G.935 showed elevated side flower mortality in certain years.
- These findings confirm that rootstock selection significantly influences the severity of frost injury.
- Choosing cold-hardy rootstocks like B.9 can help growers reduce floral bud loss, especially as warming trends lead to earlier bloom and increased overlap with spring frost risk.

References

Ambroise, V., S. Legay, G. Guerriero, J.F. Hausman, A. Cuypers, and K. Sergeant. 2020. "The Roots of Plant Frost Hardiness and Tolerance." *Plant and Cell Physiology* 61: 3–20.

Hummel, R., and M. Ophardt. 2016. "Environmental Injury: Cold Temperature Injury of Landscape Woody Ornamentals (Home Garden Series)." Washington State University Extension.

Jahed, K.R., A.K. Saini, and S.M. Sherif. 2023. "Coping with the Cold: Unveiling Cryoprotectants, Molecular Signaling Pathways, and Strategies for Cold Stress Resilience." *Frontiers in Plant Science* 14: 1246093.

Michigan State University. 2021. "Picture Table of Critical Spring Temperatures for Tree Fruit Bud Development Stages." MSU Extension Fruit & Nuts.

North, M.G., and A.P. Kovaleski. 2023. "Time to Budbreak Is Not Enough: Cold Hardiness Evaluation Is Necessary in Dormancy and Spring Phenology Studies." *Annals of Botany* 133: 217–224.

Rys, M., E. Pociecha, J. Oliwa, A. Ostrowska, B. Jurczyk, D. Saja, and A. Janeczko. 2020. "Deacclimation of Winter Oilseed Rape—Insight into Physiological Changes." *Agronomy* 10: 1565.

Saini, A.K., K.R. Jahed, D.F. Neres, R.C. Wright, and S.M. Sherif. 2025. "Investigating Frost Response, Rootstock-Dependent Cold Tolerance, and Floral Bud Mortality in Apple Cultivars through Transcriptomic Insights." *Plant Stress* 16: 100829.

Sherif, S.M. 2022. "Rootstock Effects on Tree Growth and Yield of 'Honeycrisp' Apple under Virginia State Climatic Conditions." *Virginia Cooperative Extension Publication,* SPES-398.

USDA. 2023. "USDA Unveils Updated Plant Hardiness Zone Map." U.S. Department of Agriculture, *Agricultural Research Service News Release*, 15 Nov.

Yushkov, A.N., N.N. Savelyeva, A.S. Zemisov, V.V. Chivilev, and A.V. Vislobokov. 2020. "Potential for Resistance of Ornamental Apple Varieties and Forms to Low Temperatures." *Fruit and Berry Growing of Russia* 60(1): 81–86.

Zhang, S., C. Gottschalk, and S. van Nocker. 2019. "Genetic Mechanisms in the Repression of Flowering by Gibberellins in Apple (Malus × Domestica Borkh.)." *BMC Genomics* 20: 747.

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