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Blackheart Injury in 'Starkspur Supreme Delicious' on Nine Rootstocks in the 1980-1981 NC-140 Cooperative Planting

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Abstract

Blackheart was measured at 25 cm above the soil surface in trees in the NC-140 'Starkspur Supreme Delicious' plantings located in Iowa, Ohio, Quebec, Tennessee, and Virginia after at least ten years of growth. Trees at all five locations exhibited blackheart injury. However, trees grown in Iowa, under the coldest climatic conditions, had the greatest amount of blackheart. Trees grown in Ohio and Quebec were intermediate in blackheart injury, while those grown in Tennessee and Virginia, under mild winter conditions, had less injury. Overall, M.7 EMLA and OAR.1 trees had greater blackheart injury than M.9 and Ottawa 3 (O.3) trees. All MAC.24 trees were killed in Iowa in 1986 due to a November freeze and all M.27 EMLA trees in Ohio were dead by the spring of 1989 due to severe frost heaving conditions.

Introduction

Blackheart is a type of winter injury in which xylem ray parenchyma cells are killed and vessel elements are occluded, but the cambial tissue remains uninjured (22). The typical symptom of blackheart is xylem browning, which is the result of the supercooled fraction of intracellular water freezing in the ray parenchyma cells (18, 19). Steinmetz (21) reported that if 50% or more of the parenchyma cells are killed, branches are not likely to remain alive, but if 20% or less are injured, recovery will generally occur. Thus, even though these injured trees may exhibit xylem browning internally, they may appear uninjured or produce limited vegetative growth in subsequent growing seasons (15). Blackheart injury has also been associated with a loss of productivity, although this has not been documented in the literature (18).

Blackheart is a common problem in many genera of woody plants in both temperate and sub-tropical regions of the world (10). Injury may be the result of a rapid drop in temperature in the fall, prior to vegetative maturity, or later during winter (1, 2). Warm temperatures immediately preceding a cold exposure appear to increase the severity of the injury (10, 15). Trees are also more susceptible to blackheart injury when they are young (1).

Genetic and cultural factors, such as the tree nutrient status, orchard floor management, irrigation practices, pest control, and pruning also influence the cold hardiness of the tree (15, 17, 24, 25). Several researchers have reported that rootstocks affect the low temperature resistance of the scion (6, 7, 11, 12, 23). Apple cultivars also vary in their capacity to withstand winter injury when compared on the same rootstock (20).

The purpose of this study was to determine the relative resistance of various rootstocks to blackheart injury in the NC-140 cooperative apple plantings located in Iowa, Ohio, Quebec, Tennessee, and Virginia.

Materials and Methods

Apple plantings were established in 1980-1981 and maintained at Ames, Iowa; Wooster, Ohio; Frelighsburg, Quebec; Crossville, Tennessee; and Blacksburg, Virginia according to the guidelines established by the NC-140 committee (13). In this planting, 'Starkspur Supreme Delicious' was the scion on the following rootstocks: MAC.9, MAC.24, M.7 EMLA, M.9, M.9 EMLA, M.26 EMLA, M.27 EMLA, OAR.1, and O.3. In November 1989, blackheart injury was recorded for all remaining trees at each location, except Ohio and Quebec, where data were obtained in the spring of 1990. At 25 cm above the soil surface, the percentage of blackheart injury was determined by measuring the diameter of the xylem at the widest point and then taking a second diameter measurement at a 90° angle from the mid-point of the first measurement. Similar measurements were recorded for the discolored xylem tissue exhibiting blackheart injury. Diameters of the discolored xylem and the total xylem were then averaged and the area of the blackheart injury as a percent of the total xylem area was calculated. Data were subjected to an analysis of variance and means were separated by a least significant difference (LSD) test.

Results and Discussion

Low temperature episodes occurred at each location during the ten year period that data were recorded (Table 1). In general, Iowa had the most severe weather conditions with temperatures ≤ -30°C during four winters. During March 1984, -21.1°C was recorded following almost a month of day-time temperatures above freezing. Other extreme temperatures were recorded in December 1985, in early November 1986 before trees were acclimated, and in February 1989 after a period of mild temperatures. Dead spurs were observed in the spring after each of the harsh winters (Domoto, unpublished data). Trees in the Quebec planting were exposed to extremely low temperatures with an intermittent warm period in the first winter after planting. During December 1980 and January 1981, temperatures fell to -33°C and -36°C, respectively (8). In Ohio, the lowest temperature recorded during the ten year period was -37°C in January 1990. However, the temperature fell to -25°C in December 1983 following a period of warm weather (Table 2). This low temperature episode caused significant loss of young trees on M.7 and other fruit trees in Ohio (3) and most likely resulted in some of the injury observed in this planting. Temperatures were relatively mild in Tennessee and Virginia as compared to those at other locations. In Tennessee, the lowest monthly minimum temperature was -32°C in January 1985 following mild fall weather, whereas the warmest minimum temperature (4°C) was re-

Table 1. Minimum monthly temperatures (°C) at five locations from November 1980 through March 1990.

Month	Year	IA[z]	OH	QUE	TN	VA
November	1980	-14	- 9	-13	--[y]	- 8
December	1980	-24	-19	-33	--	-12
January	1981	-21	-23	-36	--	-11
February	1981	-29	-21	-21	--	-20
March	1981	-13	-11	-16	--	-15
November	1981	-10	- 3	-11	- 9	- 9
December	1981	-24	-12	-18	-18	- 4
January	1982	-33	-28	-31	-27	-19
February	1982	-29	-21	-20	-14	- 7
March	1982	-21	-14	-22	- 9	- 9
November	1982	-14	- 6	-15	- 7	- 9
December	1982	-24	-15	-25	-24	-14
January	1983	-23	-17	-24	-12	-25
February	1983	-28	-14	-24	-11	-11
March	1983	-13	- 8	-13	- 8	-11
November	1983	-12	- 6	-10	- 6	- 9
December	1983	-29	-25	-26	-24	-17
January	1984	-31	-27	-26	-24	-17
February	1984	-23	-17	-22	-18	-13
March	1984	-21	-21	-25	-12	- 8
November	1984	-11	- 8	-13	- 9	-10
December	1984	-18	-14	-24	-17	-22
January	1985	-29	-28	-25	-32	-19
February	1985	-24	-25	-28	-16	-12
March	1985	- 5	- 7	-18	- 6	-11
November	1985	-19	- 5	-10	4	-11
December	1985	-32	-19	-27	-18	-14
January	1986	-27	-18	-27	-22	-28
February	1986	-27	-16	-23	-17	-13
March	1986	-16	-18	-22	- 9	- 6
November	1986	-20	-12	-12	4	- 6
December	1986	-25	-11	-20	- 8	-22
January	1987	-23	-20	-23	-17	-23
February	1987	-13	-14	-28	-10	-17
March	1987	-13	- 9	-19	- 6	-13
November	1987	- 7	-12	-15	- 8	-13
December	1987	-17	-11	-22	- 9	-12
January	1988	-27	-20	-29	-16	-20
February	1988	-30	-14	-24	-18	-11
March	1988	-11	- 9	-19	-12	-12
November	1988	-12	-11	- 9	- 8	- 8
December	1988	-19	-12	-23	-13	-11
January	1989	-16	-13	-26	- 8	-18
February	1989	-27	-16	-24	-17	-19
March	1989	-14	-11	-27	- 6	- 9
November	1989	--	- 8	-15	--	--
December	1989	--	-28	-27	--	--
January	1990	--	-37	-21	--	--
February	1990	--	-11	-19	--	--
March	1990	--	-11	-19	--	--

[z]IA = Iowa, OH = Ohio, QUE = Quebec, TN = Tennessee, VA = Virginia.
[y]Trees were planted in spring of 1981.

corded in November 1986. During the ten years data were recorded in Virginia, trees were exposed to temperatures below -25°C during only one month (January 1986).

Blackheart injury was observed in trees at all sites (Table 2). In general, trees grown in Iowa had significantly greater blackheart injury than those grown in other locations (analysis not shown). Ohio and Quebec trees were intermediate in injury, whereas those grown in Tennessee and Virginia had the least amount of damaged xylem tissue.

In Iowa, O.3 and M.26 EMLA trees had less blackheart injury than OAR.1, MAC.9, M.7 EMLA, and M.27 EMLA trees. Blackheart was not recorded for MAC.24 trees due to the loss of all ten trees on this rootstock after severe low temperature exposure in November 1987. By this spring of 1988, all MAC.24 trees exhibited 100% trunk injury in this trial (Domoto, unpublished data).

Rootstocks did not differ in blackheart injury in the Tennessee or Ohio plantings. However, data were not recorded on M.27 EMLA trees in Ohio due to the death of all these trees by the spring of 1989. This loss of M.27 EMLA trees may be attributed to root injury associated with the severe frost heaving that exposed much of the root system. Trees on other rootstocks in the Ohio planting were not similarly affected.

In the Quebec planting, M.9 and O.3 trees had less blackheart injury than M.7 EMLA, OAR.1, and MAC.9 trees. In contrast, MAC.9, O.3, and M.27 EMLA trees had less blackheart than OAR.1 and M.9 EMLA trees at the Virginia location.

When blackheart injury from all rootstocks was analyzed across all locations, M.9 and O.3 trees were less susceptible to blackheart than M.7 EMLA and OAR.1 trees (Table 3). Mean separation of blackheart injury could not be performed on M.27 EMLA and MAC.24 trees due to the complete

Table 2. Percent blackheart injury of 'Starkspur Supreme Delicious' on nine rootstocks planted in the 1980-1981 NC-140 cooperative rootstock trial at five locations.

Rootstock	IA[z]	OH	QUE	TN	VA
OAR.1	44.3a[y]	19.8a	30.9ab	3.8a	12.2a
MAC.9	43.1a	22.3a	30.7ab	2.0a	5.9b
M.7 EMLA	43.1a	30.4a	35.5a	4.1a	8.0ab
M.27 EMLA	42.9a	---	27.8abc	7.4a	3.8b
M.9 EMLA	32.9ab	24.0a	25.2abcd	5.1a	12.1a
M.9	32.6ab	20.9a	18.8cd	3.6a	7.6ab
O.3	28.9b	25.4a	17.3d	1.6a	3.9b
M.26 EMLA	28.7b	22.4a	24.6bcd	3.0a	9.9ab
MAC.24	---	22.4a	27.2abcd	7.1a	8.2ab

[z]IA = Iowa, OH = Ohio, QUE = Quebec, TN = Tennessee, VA = Virginia.
[y]Mean separation within columns by LSD test, 5% level.

loss of these trees at two different locations. Although all the MAC.24 trees were killed by low temperatures in Iowa, trees on this rootstock did not appear to have greater blackheart injury than any other rootstocks at other sites included in this study. Additionally, M.27 EMLA were not particularly susceptible to injury at any of the locations, except Ohio, where all trees were killed, and in Iowa, where M.27 EMLA trees had greater xylem injury than those on two other rootstocks. Although blackheart injury data from the Illinois planting was not included in this study, 100% loss also recorded for M.27 EMLA trees (14). This loss may also be attributed to frost heaving the shallow root system out of the ground.

Several researchers have ranked the relative cold hardiness of rootstocks (4, 5, 6, 7, 11, 12, 26). Generally, M.7 is classified as a very tender rootstock, M.9 as tender, M.26 as moderately hardy, and O.3 as very hardy (9, 16). However, this type of ranking does not identify rootstocks, such as M.9 and *Malus robusta* 5, that have good hardiness in the fall due to early acclimation to low temperatures, but are susceptible to injury during the midwinter thaws (7, Domoto, unpublished data). Other rootstocks, such as M.26 and MM.106, are tardy in the induction of acclimation in the fall, but retain low temperature resistance into spring. Moreover, it is difficult to compare much of the previous work with this study due to differences in experimental procedures. For example, most of the previous work has been conducted on young tissue (generally one to two-year-old wood) and often oxidative browning ratings or conductivity measurements were not confined to xylem, but also included other stem tissues. In hardiness evaluations conducted by Warmund and Slater (23), the xylem of MAC.9 had greater injury

Table 3. Percent blackheart injury of 'Starkspur Supreme Delicious' on seven rootstocks analyzed across five locations.

Rootstock	% Blackheart Injury[z]
M.7 EMLA	24.2a
OAR.1	22.2ab
MAC.9	20.8abc
M.9 EMLA	19.9abc
M.26 EMLA	17.7bc
M.9	16.7c
O.3	15.4c

[z]Mean separation by LSD test, 5% level.

than that of M.7 EMLA, M.9 EMLA, M.26 EMLA when two-year-old wood was sampled from selected rootstocks in the 1980-1981 NC-140 planting in December 1986. However, OAR.1 and MAC.9 did not differ in xylem injury. Thus, it is difficult to relate blackheart injury exhibited in ten-year-old trees in this study to low temperature injury ratings reported in the literature.

In conclusion, all trees planted in the 1980-1981 NC-140 'Starkspur Supreme Delicious' trial exhibited blackheart injury at all five locations by the spring of 1990. Across all locations, M.9 and O.3 trees had less blackheart injury than M.7 EMLA and OAR.1 trees. All MAC.24 trees in Iowa exhibited trunk injury and subsequently died as a result of low temperature exposure. Additionally, M.27 EMLA trees were killed after severe frost heaving occurred in the Ohio planting.

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