

1 What is Rose Rosette Disease?

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Abstract. Rose Rosette Disease (RRD) is caused by a negative-sense RNA virus (genus *Emaravirus*) which is vectored by a wind transported eriophyid mite (*Phyllocoptes fructiphilus*). Symptoms include witches broom/rosette type growth, excessive prickles (thorns), discolored and distorted growth and, unlike most other rose diseases, usually results in plant death. RRD is endemic to North America and was first described in Manitoba, Wyoming, and California in the 1940s. It has spread east with the aid of a naturalized rose species host and has become epidemic from the Great Plains to the East Coast of North America on garden roses in home and commercial landscapes where losses have been high. The disease was suggested to be caused by a virus from the beginning, but only recently has this been confirmed and the virus identified. The presence of the vector mite on roses has been associated with RRD since the first symptoms were described. However, more recently the mite was demonstrated to be the vector of the disease and confirmed to transmit the virus itself. As a result of the RRD epidemic in North America and its effects on the national production and consumer markets for roses, a research team comprising five major universities (TX, FL, TN, OK, DE), a dozen growers and nurseries (all regions), 6 rose breeding programs (CA, WI, TX, PA), the major rose testing programs (Earth Kind and AGRS), the major rose organization (American Rose Society), and the major

trade organization AmericanHort.has formed. This research project has been funded by the Specialty Crops Research Initiative through the US Department of Agriculture with the short term objective of improving and disseminating Best Management Practices and the long term goal of identifying additional sources of resistance and developing the genetic tools to quickly transfer resistance into the elite commercial rose germplasm.

Rose Rosette Disease (RRD) is caused by a negative-sense RNA virus (genus Emaravirus) which is vectored by a wind dispersed eriophyid mite (*Phyllocoptes fructiphilus*) (Laney et al., 2011; Di Bello et al., 2015). Symptoms on roses include witches broom/rosette type growth, excessive thorniness, discolored and distorted growth. Unlike most other rose diseases, RRD usually results in plant death (Windham et al., 2014; Olson et al., 2015). Since being identified in the western USA and Canada, it has spread east with the aid of *Rosa multiflora*, a naturalized rose species host, and has become widespread from the Great Plains to the East Coast of North America (Amrine, 2002). This epidemic has spread to garden roses in home and commercial landscapes where losses have been high. The popularity of landscape roses in gardens has increased greatly in recent years resulting in widespread use of this type of rose in both home and commercial landscapes (Pemberton and Karlik, 2015). This and the occurrence of the disease in poorly managed landscapes where plants are not scouted and rogued have no doubt contributed to the spread of this deadly disease (Windham et al., 2014; Olson et al., 2015). The degree of plant loss threatens the use of garden roses by consumers and the rose production industry itself.

RRD is endemic to North America and was first described in Manitoba, Wyoming, and California in the 1940s. In 1940, Connors (1941) observed a “Witches’ Broom (?virus)” symptom with a greatly increased number of spines affecting canes of an unnamed species of rose in Morden, Manitoba. Thomas and Scott (1953) reported receiving diseased specimens of *R. rubrifolia* grown as an ornamental from Lander, Wyoming in 1941. A specimen from near the same location, but on an unidentified native rose was received in 1942. Also in 1942, the same authors reported a specimen collection with similar symptoms from “a native rose, possibly *R. pisocarpa*, near Carrville in a mountainous area of Trinity County, California”. Symptoms

80 included witches' broom type growth, an indefinite chlorotic pattern in leaves, misshapen leaflets
81 and flowers, and an increase in thorniness. They believed both of these collections to be
82 representative of the same disease which they referred to as Rosette of Rose. By the late 1960s,
83 RRD symptoms were found in California on the native rose *R. woodsii* var. *ultramontane*
84 (Wagnon and Nichols, 1966; Wagnon and Nichols, 1970).

85 Symptoms similar to those reported by Thomas and Scott (1953) were recognized at the
86 University of Nebraska North Platte Experiment Station in 1957 by Viehmeyer (1961). By 1959,
87 a 4 to 5 acre block of rose-breeding stock at the Station was heavily infected (Allington et al.,
88 1968). In the same area, Viehmeyer (1961) indicated that the disease had been found in an area
89 about two hundred miles long and fifty miles wide. The same author also described the
90 destruction of several miles of infected *R. multiflora* hedge in this particular area along with
91 other centers of infestation. In addition to the symptoms described above, Allington, et al.
92 (1968) noted the red leaf coloration in *R. multiflora* and a thickening of new, infected stems in
93 most of the cultivars or species with which they worked.

94 In 1976, RRD was reported in Kansas (Crowe, 1983) and reports increased in the late
95 1970s in eastern Kansas and western Missouri. Symptoms were noted on rose hybrids in urban
96 areas and on rose hybrids and *R. multiflora* hedges in rural areas. By 1982, symptoms were
97 reported on cultivated hybrid roses in eastern Oklahoma (Crowe, 1983) and on both cultivated
98 rose hybrids and *R. multiflora* hedges in northwestern Arkansas (Gergerich and Kim, 1983).

99 The first report of RRD east of the Mississippi River was found by Hindal et al. (1988)
100 who described infestations in naturalized stands of *R. multiflora* in Illinois (1985), Kentucky
101 (1985), and Indiana (1986). In 1990, the first report came from Texas where it was found in
102 production fields in east Texas where *R. multiflora* was used as a rootstock for garden rose

production (Ong, et al., 2015; Philley, 1995). By 1994, RRD distribution was as far east as Tennessee, Ohio, Pennsylvania, and West Virginia (Amrine, 2002) with reports mainly concerning infections in *R. multiflora*. In 1996, it was found in Maryland on *R. multiflora* (Tipping and Sindermann, 2000). In recent years, RRD has spread into garden rose plantings via the mite vector across the Midwest and Eastern USA resulting in huge losses. In addition, it was found on a hybrid garden rose in a nursery in Florida in 2013 (Babu et al., 2014).

Abundantly apparent is the fact that the spread of RRD from western North America to the east has occurred through naturalized stands of *R. multiflora*. The history and status of the infestation of this introduced plant species along with the ecological damage it has caused has been well reviewed (Amrine 2002; Amrine and Stasny, 1993). *Rosa multiflora* is native to eastern China, Japan, and Korea and was introduced into North America in the 1800s for use as a rootstock, and also for wildlife, erosion control, “living fences”, and informal hedges (Amrine, 2002; Hindal et al., 1988; Hong et al., 2012). It soon spread from the original plantings and is now listed as a noxious weed in at least ten states (Amrine and Stasny, 1993). The use of RRD as a biological control for *R. multiflora* has been proposed and studied (Amrine, 2002; Amrine and Stasny, 1993; Epstein and Hill, 1999). However, this work has been opposed by the American Rose Society and by rosarians in general (Amrine, 2002).

The determination of the disease agent that causes RRD also has a long history. In 1953, Thomas and Scott suggested a virus as the cause of a witches broom symptom in rose and demonstrated graft transmission of the disease agent. Allington et al. (1968) referred to this disease agent as Rose Rosette Virus (RRV). Many years later, Gergerich and Kim (1983) reported double membrane-bound virus-like particles in cells of rose plant tissue infected with RRD. Doudrick et al. (1987) extracted the infectious agent and demonstrated transmission by

drop inoculation or grafting. In 1990, Di et al. found four unique virus-like double-stranded RNAs associated with RRD symptoms in *R. multiflora*. These were graft transmissible, but not through seed or fruit. Finally, Laney et al. (2011) characterized the causal disease agent as Rose Rosette Virus, a negative-sense RNA virus and new member of the genus *Emaravirus*. The presence of the virus was perfectly correlated with RRD disease symptoms.

About the same time that Connors (1941) observed the witches broom symptom on rose in Manitoba, Kiefer (1940) reported the presence of the eriophyid mite *Phyllocoptes fructiphilus* on *R. californica* in California. There is no indication in the literature that either author knew of the other's observations. Indeed, *R. californica* appears to be resistant to RRD when inoculated by grafting (Thomas and Scott, 1953). By 1968, Allington et al. reported this Rose Mite as a vector for infection of *R. multiflora* with RRD. Twenty years later, Amrine et al. (1988) confirmed the mite as a vector for RRD infection. Root graft experiments indicated that the infection was due to a virus-like agent and not a reaction to mite feeding. Kassir and Amrine (1990) demonstrated that mites survive only on green living tissue and Zhao (2000) reported that mites develop only on tender rapidly growing shoots and are disseminated aurally. Recently, Di Bello et al. (2015) reported the presence of RRV in rose mites and demonstrated mite transmission of the viral disease agent that causes RRD.

Thus, the three players in this disease epidemic are described: the virus pathogen, the mite vector, and the reservoir of a host plant. Of interest is the fact that the RRD epidemic was not caused by the introduction of a causal disease agent or even a vector for the virus, both of which are endemic to North America. What assisted the spread of this disease from the west to the east of the continent was the reservoir of naturalized stands of a very susceptible host plant

(*R. multiflora*) that was introduced across a large geographical area for an entirely different purpose.

As a result of the RRD epidemic in North America and its effects on the national production and consumer markets for roses, a research proposal to study this disease was funded by the Specialty Crops Research Initiative through the US Department of Agriculture. The proposal was developed in collaboration with the rose industry beginning with the Rose Rosette Conference organized by *Star Roses and Plants* and the Garden Rose Council in April of 2013. At this conference, which brought together trade associations, growers, breeders, landscape management firms, botanical gardens, federal regulatory agencies, biocontrol corporations, consultants, state plant disease diagnostic laboratories and researchers from both the state and federal levels, a plan was developed to direct future research and serve as an outline for the resultant proposal. Over a period of months, a research and extension team that involved plant pathologists, rose breeders and geneticists, molecular geneticists, an entomologist, agricultural economists, marketing experts and extension personnel was developed to tackle RRD. This team is from state, federal and private organizations from Texas, Oklahoma, California, Florida, Tennessee, Delaware, Pennsylvania, Maryland, Wisconsin and Connecticut (Table 1). The rose industry also committed their resources to the project.

Thus, this project and its objectives are industry driven and initiated. It is built on a research and industry community comprising five major universities (TX, FL, TN, OK, DE), a federal research agency (USDA-ARS), a dozen growers and nurseries (all regions), six rose breeding programs (CA, WI, TX, PA), the major rose testing programs (Earth Kind and AGRS), the major rose organization (American Rose Society), and the major trade organization AmericanHort.

In the short term, this project will expand, refine and develop existing Best Management Practices (BMPs) through understanding the biology of the host-virus-vector interaction and work with AmericanHort to expand the existing information pipeline via publications, presentations and demonstrations to convey the use and value of these BMPs for managing RRD to stakeholder groups. The long term goal is to identify additional sources of resistance and the genetic tools to quickly transfer resistance into the elite commercial rose germplasm.

RRD is a major concern for growers and consumers alike. Consumers and producers will benefit from RRD resistant roses through the reduced use of chemicals (miticides) in the landscape leading to sustainable gardening and production systems. Breeding tools and approaches developed in this project will benefit breeders and producers by allowing quicker development of RRD resistant roses as well as resistance to other fungal, bacterial and viral diseases. According to our 2012-2103 survey of over 1500 consumers and industry participants, disease resistance is the most desired trait in new rose cultivars (Byrne, 2015; Waliczek, et al., 2015). Roses are one of the most economically important ornamental plants in North America so that the findings from these studies will strengthen this industry and support the use of a sustainable and much loved plant by consumers across the continent.

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286 Table 1. Investigators and key collaborators working on the Specialty Crop Initiative Project
 287 Combating Rose Rosette: Short Term and Long Term Approaches

Name	Specialty	Responsibility	Location
David H. Byrne, Project Director	Rose Breeding and Genetics	Rose Breeding and Genetics	Department of Horticultural Sciences, Texas A&M University, College Station, TX
Mark Windham	Plant Pathology	Screening for resistance, BMP	Entomology and Plant Pathology Department, University of Tennessee, Knoxville, TN
Brent Pemberton	Plant Physiology, Horticulturist	Outreach, rose evaluation trials	Texas A&M AgriLife Research and Extension Center at Overton, TX
Frank Hale	Entomologist	BMP	Soil, Plant, and Pest Center, The University of Tennessee, Nashville, TN
Ronald Ochoa	Entomologist	Mite-plant interactions	Systematic Entomology Laboratory, USDA/ARS, Beltsville, MD
Mathews Paret	Plant Pathologist	Diagnostic techniques	North Florida Research and Education Center, Quincy, FL

Francisco Ochoa Corona	Plant Pathologist	Diagnostic techniques	Department of Entomology and Plant Pathology, Oklahoma State University, Stillwater, OK
John Hammond	Plant Pathologist	Diagnostic techniques	Floral and Nursery Plants Research Unit, USDA/ARS, Beltsville, MD
Ramon Jordan	Plant Pathologist	Diagnostic techniques	Floral and Nursery Plants Research Unit, USDA/ARS, Beltsville, MD
Patricia Klein	Molecular Biologist	Molecular genetics, marker technology	Department of Horticultural Sciences, Texas A&M University, College Station, TX
Tom Evans	Plant Pathology, Genetics	Screening for resistance	Department of Plant and Soil Sciences, University of Delaware, Newark, DE

Table 1. Continued.

Jennifer Olson	Plant Pathologist	Outreach, Diagnostics validation, Screening for resistance	Department of Entomology and Plant Pathology, Oklahoma State University, Stillwater, OK
Kevin Ong	Plant Pathologist	Outreach, Monitoring Network, Diagnostics validation	The Texas Plant Disease Diagnostic Laboratory, Texas A&M AgriLife Extension, College Station, TX
Gary Knox	Extension Horticulturist	Outreach	North Florida Research and Education Center, Quincy, FL
Alan Windham	Extension Plant Pathologist	Outreach, Social Media	Soil, Plant, and Pest Center, The University of Tennessee, Nashville, TN
Marco Palma	Extension Economist	Marketing and Economics	Department of Agricultural Economics, Texas A&M University, College Station, TX

Charles Hall	Extension Specialist	Marketing and Economics	Department of Horticultural Sciences, Texas A&M University, College Station, TX
Luis Ribera	Economics- Management	Marketing and Economics	Department of Agricultural Economics, Texas A&M AgriLife Research & Extension Center, Weslaco, TX
Christian Bedard	Rose Breeding	Population creation	Weeks Roses, Pomona, CA
Ping Lim	Rose Breeding	Population creation	Altman Plants, Vista, CA
Jim Sproul	Rose Breeding	Population creation	Roses by Design, Bakersfield, CA
Michele Scheiber	Rose Breeding	Population creation	Star Roses and Plants, West Grove, PA
David Zlesak	Rose Breeding	Population creation	Department of Plant and Earth Sciences, University of Wisconsin-River Falls, WI

Don Holeman	Rose Breeding	Population creation	Enfield, CT
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Table 1. Continued.

Marco Bink	Bioinformatics	Genetic analysis	Plant Research Institute, Wageningen, The Netherlands
Eric van de Weg	Bioinformatics	Genetic analysis	Plant Research Institute, Wageningen, The Netherlands

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