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A Three Year Study of Winter Hardiness and Blackspot Resistance (*Diplocaron rosae* Wolf) of Roses in Two Climatically Different Environments

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ABSTRACT

Most of the garden rose cultivars available today are not fully winter hardy in cooler climates. Besides insufficient winter hardiness, susceptibility to multiple fungal diseases is a major problem as it reduces the ornamental value as well as the vigour of the infected plant. Blackspot, caused by the fungus *Diplocarpon rosae*, is often regarded as the most destructive disease of outdoor grown roses. A cooperative field trial in Balsgård, Sweden (56° N; 14° E) and Morden, Canada (49° N; 98° W) was performed from 1995 to 1999 with the objective of studying the variation in winter survival, winter injury and blackspot resistance among a common group of rose genotypes chosen to represent a diversity of rose germplasm. Significant differences were obtained between genotypes regarding winter injury and blackspot infection at both sites. Differences between the cultivars were also noted for the diseases leaf spot, powdery mildew and rust. The survival rate at Balsgård was lower compared to Morden after the first winter. This was most striking for cultivars belonging to the floribunda and polyantha horticultural groups. Absence of snow cover is a likely reason for the higher mortality rate at Balsgård. Significant differences were also obtained for amount of winter injury on surviving genotypes. Surviving genotypes at Balsgård suffered less winter injury compared to Morden. The most hardy genotypes at both sites belonged to the alba, damask and hybrid gallica horticultural groups and species within the sections *Rosa* (=*Cinnamomeae*) and *Synstylae*. In addition, the same groups and sections contained the most blackspot tolerant genotypes. The degree of blackspot infection was the highest in Morden all three years of the study and possible explanations are discussed, e.g. existence of different races of the fungus. The results obtained indicated a competition between different fungi on rose plants. Significant correlations between high blackspot infection rates and a high degree of winter injury after the following winter were also observed.

Keywords: *Diplocarpon rosae*, leaf spot, *Marssonina rosae*, powdery mildew, rust, winter injury, winter survival

INTRODUCTION

Roses are among the most popular ornamental flowers in the world and have been cultivated and admired for over 4700 years. Around 130 rose species have been described, all native to the northern hemisphere (Gustavsson 1998). Many of them originate from eastern Asia and are relatively winter hardy. Nevertheless, most of the germplasm involved in the many cultivated garden roses comes from the southern part of the range for the genus (Marshall and Collicutt 1992), which unfortunately led to few cultivars being fully winter hardy in cooler climates.

Winter survival and the degree of winter injury of a rose plant depends on several factors. One is the ability to acclimate to cold in the fall, but mid-winter hardiness and de-acclimation are important factors as well. Mid-winter hardiness is the lowest temperature a plant can survive without injury after it has gone through the acclimation process and has reached its maximum cold hardiness level. De-acclimation refers to a decrease in the hardiness of plant tissues in response to warming temperatures in late winter and early spring.

Acclimation of plants is a two-stage process. The first stage is triggered by decreasing day length (Fuchigami *et al*. 1982) and results in partial hardiness. The second stage is initiated by subfreezing temperatures and results in full hardiness and acclimation of the plant (Rose and Smith, http://ohioline.osu.edu/hyg-fact/1000/1016.html). Temperatures down to –3°C may be necessary for maximum cold hardening (Salisbury and Ross 1985). For many plant species, the shortened photoperiod of late summer initiates the hardening process by slowing vegetative growth. The time it takes for plant growth to stop differs widely for different species. The differences are due to hormonal balance in the plants controlled by day length and modified by temperature. The leaves are the receptors of the short day signal (Rose and Smith, http://ohioline.osu.edu/hyg-fact/1000/1016.html). After growth has stopped, the short day photoperiod triggers a hardening signal that is transferred from the leaves to the stems and branches. Timing and hardening rate can be altered by temperature, however, the day length is predictable by calendar dates and latitude. Therefore the hardening response in a single plant may vary from year to year because of temperature differences (Rose and Smith, http://ohioline.osu.edu/hyg-fact/1000/1016.html).

Most plants require both short photoperiods and lower temperatures to develop full hardiness, but some harden only in response to low temperature regardless of photoperiod. Herbaceous plants tend to be more sensitive to photoperiod, whereas woody plants tend to be more sensitive to cold temperatures. During acclimation, different physiological changes take place, one is the accumulation of various solutes in the cell, which decrease the risk of freezing by lowering the osmotic potential (Galston *et al*. 1980). According to Levitt (1980), natural sugar content in plants usually increases with increased cold tolerance. Modification of proteins and changes in cell membrane permeability are also associated with an increase in cold hardiness (Rose

Received: 26 August, 2008. Accepted: 3 May, 2009.

Original Research Paper

and Smith, http://ohioline.osu.edu/hyg-fact/1000/1016.html). The need for an acclimation period is a universal requirement for all plants. Nevertheless, not all plants succeed to acclimate which was demonstrated by Karam and Sullivan (1991). According to their study, survival of buds increased by sucrose treatment during acclimation in a cold-hardy species *Rosa fedtschenkoana* Regel, but not in a cold-sensitive hybrid tea rose 'Jack Frost'. Freezing without prior acclimation was lethal to both the sensitive cultivar and the hardy species. However, cold-hardiness was not improved by acclimation at low temperature for 'Jack Frost' which indicates that 'Jack Frost' probably belongs to a category of plants that fail to effectively acclimate and remains very sensitive to freezing. The timing and rate of acclimation have been found to be the limiting factors for the winter survivability of seven rose cultivars in a trial performed in Minnesota, USA (Zuzek *et al.* 1995). The same study showed that differences in minimum winter temperatures are not an effective way to explain annual differences in injury levels as the smallest amount of injury was observed after the coldest winter in this trial. Temperature comparisons of late fall and early winter offered a more feasible explanation for the differences as well as how early or late in winter the lowest temperatures occur. A gradual temperature decline during the acclimation period may allow plants to escape injury.

Factors that promote more rapid growth (e.g. high nitrogen in the soil, pruning and irrigation) inhibit the acclimation process (Salisbury and Ross 1985). Exposure time to slightly below freezing temperatures needed to complete the acclimation process appears to be longer for immature than well matured tissues (Chandler 1954). Rapid growth (e.g. immature tissues) requires an energy source, as does the development of frost hardiness (the acclimation process) which leads to a situation of competition for energy.

Plants will be directly damaged or killed when winter minimum temperatures are too low, with respect to their inherent cold resistance. Cold damage, however, depends on several different meteorological variables like minimum and maximum temperatures, wind, rain, snow and frost-free period. The frost-free period as well as precipitation and maximum temperatures influences the time period required for the plant to reach maturity, which in turn affects the acclimation process, and thereby, the amount of cold damage. Surface snow cover protects directly against low temperatures, whereas wind increases the transpiration which can be dangerous when the frozen soil cannot provide much water (Ouellet and Sherk 1967). Preliminary results from the first two growing seasons of the present study (Carlson-Nilsson and Davidson 2000) pointed to significant differences between the trial in southern Sweden compared to the one in Manitoba, Canada, regarding winter survival and winter hardiness. Morden, Manitoba appeared to have a more favourable climate as expressed by a higher survival percentage, while Balsgård in southern Sweden displayed better winter hardiness among surviving genotypes.

Studies on winter (cold) hardiness for different rose genotypes have been performed both in field trials and under laboratory conditions (Lehmushovi 1987; Anderson 1990; Karam and Sullivan 1991; Hakam *et al.* 2000). Even if results from field trials are fully comparable only between areas with identical climatic conditions because of the large climatic influence on the amount of winter injury and survival, Karam and Sullivan (1991) argue that only long-term field testing can really identify genotypes with consistently high winter survival. In their study the aim was to develop a laboratory method able to replace the tedious and time-consuming method of identifying cold-hardy rose hybrids in field trials in a rose breeding program. Actively growing shoots were harvested and 2 cm segments were immersed in sucrose solutions of different concentrations at 4°C for periods of 1 to 4 weeks before being exposed to freezing temperatures of -5 or -10°C for 18 hr. After that, they were thawed at 4°C for 24 hr and then cultured on Murashige and Skoog medium in a growth room (approx. 24°C, 16 hr light period). Growth of buds was observed 2 weeks after culturing and used as a measurement of survival. A clear difference was observed in freezing tolerance between the three rose genotypes used in the study and it was concluded that assaying for cold hardiness could be accomplished in a laboratory environment within 2 weeks. However, it was also pointed out that this selection process may not identify the hardiest individuals in a hybrid population, but can be of value as a way to eliminate the least or moderately hardy genotypes (Karam and Sullivan 1991). Gusta *et al.* (1997), who studied winter hardiness in winter wheat, also argue that field survival is the ultimate measure of winter hardiness of a cultivar. According to them, winter kill in nature is more a function of duration of exposure to sub-lethal temperatures rather than exposure to a minimum low temperature for a short duration as programmed in a conventional freeze test. Controlled freeze tests to determine the LT_{50} (temperature at which 50% of the plants are killed) of a genotype are widely used because they allow replication over time, provide precise test temperatures and the tests can be conducted over a relatively short time period. However, Gusta *et al.* (1997) showed that two winter hardy winter wheat cultivars both had a similar LT_{50}, however one of the cultivars could not tolerate storage at either -12 or -15°C for the same length of time as the other cultivar.

Besides insufficient winter hardiness, susceptibility to fungal diseases is a major problem in many roses. Blackspot, caused by the fungus *Diplocarpon rosae* Wolf (*Marssonina rosae* (Lib.) Died.; anamorph), is often regarded as the most destructive disease in garden roses (Horst and Cloyd 2007). Infected leaves show typical dark, almost black, spots with a fringed margin. The spots are usually surrounded by chlorotic areas. In severe attacks, the spots coalesce and finally the plant is partly or completely defoliated depending on the rate of development and ability to resist the disease. Complete resistance is rare but occurs in a few species roses or species hybrids (Ballard *et al.* 1996; von Malek *et al.* 2000). Several reports of screening for resistance to blackspot, with natural infection in the field or artificial infection in inoculation trials, have been published (Palmer *et al.* 1966; Drewes-Alvarez 1992; Carlson-Nilsson 2000; Yokoya *et al.* 2000). However, a number of factors influence the results of such evaluations, and discrepancies sometimes occur between reports. Possible reasons are occurrence of different races of the fungus, age of the foliage (Xue and Davidson 1998), weather conditions and amount of accumulated inoculum (Bhandari *et al.* 1993; Carlson-Nilsson 2000).

Infection by fungal diseases causing defoliation, like blackspot, can also be indirectly responsible for much of the winter injury in roses (McClellan 1953). After defoliation the infected plants may produce new leaves and shoots, which in turn can become infected. Besides weakening the plant, new growth is produced so late in the season that it may not mature and acclimate properly. Other fungal diseases like powdery mildew, leaf spot and rust do not cause defoliation in roses as blackspot does. However, they might be indirectly responsible for part of the winter injury as well because of general weakening of the plant.

In the present study, the variation in winter survival, winter injury and blackspot resistance between different genotypes chosen to represent a broad cross section of genetic diversity in the genus *Rosa* was investigated. The aim was to **1)** find valuable germplasm to use in two breeding programs for winter hardy and disease resistant roses in climatically different environments, Balsgård, Sweden (Swedish University of Agricultural Sciences) and Morden Research Centre, Canada (Agriculture and Agri-Food Canada) and **2)** to learn more about how the climate affects winter survival, winter injury and amount of blackspot and other fungal disease infection on a common group of diverse rose genotypes.

MATERIALS AND METHODS

Plant material

Forty-two genotypes, representing different horticultural/taxonomic groups, were selected for this study (**Table 1**). Several of the genotypes had been reported to show some degree of tolerance to blackspot disease according to personal communication with professional rose growers and experts as well as literature findings (e.g. Gustavsson 1998).

Uniform plants were obtained through propagation of softwood stem cuttings in the spring of 1995. Until planting in November 1995 (Sweden) and May 1996 (Canada), the plants were grown in pots (commercial soil mix "Hasselfors Garden") in a greenhouse and later on in a frame yard. The plants for Canada were overwintered in Sweden and shipped to Canada in April 1996.

Own root plants were chosen instead of grafted plants on a common rootstock. The study was performed to support two breeding programs with the mission of developing hardy, adapted roses capable of growing well on their own roots. Both in Canada and Sweden own root roses are growing in popularity. Therefore it was of interest to select rose cultivars that did well on their own roots to use as parents in order to generate offspring that would likely also be efficient own root growers.

Field trials

One trial was established at Balsgård (56° N; 14° E) Sweden, and one at AAFC Morden Research Centre (49° N; 98° E), Canada. The soil at Balsgård is loamy sand and at Morden clay loam. The experiment was arranged in a randomized complete block design consisting of 4 blocks with 8 rows each, 3.5 m apart. Each block included 3 randomized plants of each genotype (except for the cultivars *R. gallica officinalis* Thory, 'Président de Sèze' and *R. gallica versicolor* L. which were represented by fewer plants), planted 0.8 m apart within rows. For exact numbers of the different genotypes included at the very start of the trial at the two sites see **Tables 1** and **2**.

No special winter protection was administered. Fungicides were not applied during the course of the study. The plots were weeded by use of herbicides and hand hoeing. Irrigation was only undertaken in periods with prolonged drought. No fertilizers were used in Morden, whereas 12-5-14 NPK (Complesal, Scotts Company, Ohio, USA) at 300 kg/ha was added yearly at Balsgård. No mulch was used in the trials.

Climatic data was collected from weather observation stations as close as possible to the field trials (**Tables 3** to **6**). In 1995, the weather data for Balsgård were obtained from Kristianstad-Everöd airport, approximately 20 km from the field trial. In 1996, this observation station was closed down and data had to be taken from Osby, about 30 km from the trial. In January 1997, an old observation station was re-opened in Kristianstad approximately 12 km from the trial and that data is reported. The weather data for Morden were collected from an Environment Canada weather station located right at the Morden site.

Assessments of plants in field trials

After the winter of 1995/96 (not included in the assessments) very weak or dead plants at Balsgård were replaced with additional plants of the same genotype kept in cold storage over the winter. However, in some cases replacement was impossible because of lack of plant material and some of the replacement plants also died before the first assessments were made in 1996. Therefore, 10 plants were missing at Balsgård already at the start of the study (**Table 1**). In Morden, 42 plants died before the first assessments (**Table 2**).

Winter survival was determined at both Balsgård and Morden the winters of 1996/97–1998/99 by counting the number of surviving plants each spring after budbreak and onset of growth.

Winter injury (overall plant injury) was rated in 1997-1999 according to Davidson *et al*. (1994), where 0=dead plant and 10=no injury and good plant growth.

The fungal diseases blackspot, leaf spot, powdery mildew and rust were assessed visually. Main attention was given to blackspot. Different fungal diseases tend to start their infection process at different parts of the rose plant. Blackspot infections seem to start at the lower parts of plants and work its way upwards, whereas the first infections of powdery mildew more often can be noticed at the top of plants. Rust and leaf spot seems to be more randomly distributed over plants. To be able to study the infection progress of blackspot in more detail (data not shown) we assessed blackspot infection of different parts of the plant separately for this disease. In 1996, which was the first year of fungal scoring, blackspot was the only disease studied. Assessments were made on the whole plant and the lower, middle and upper parts were rated separately. Each level was rated F=free of disease, L=light infection (trace to 20% of the leaf/stem area infected), M=moderate infection (21-50%) or S=severe (51-100%). Each score was given a numeric value (F=0, L=1, M=2 and S=3) and the numeric scores for the 3 levels of the plant were added together to give a cumulative score for each plant. However, we found out that this method was far too time consuming as the plants grew larger. Therefore, in 1997 and 1998, blackspot was instead rated only on one dominant shoot originating from old wood or from below ground (current year's growth). Each shoot was divided in a lower (I) and an upper half (II) which were scored separately according to the same scale as in 1996. To be comparable to the results from 1996 the scores for the 2 levels were combined and transformed into numeric values, 0 to 9, according to **Table 7**. For values 1, 3, 4, 6, 7 and 8 the order of the ratings was of no importance (e.g. L/F got the same values as F/L). The date for the assessments in 1996 was chosen to be identical at both sites (mid October), whereas the dates for the other two years were selected based on results from weekly blackspot assessments on three (91/104-1, 91/109-1, 'Comte de Chambord' in Sweden and 91/107-1, 91/109-1, 'Chloris' in Canada) and five (91/104-1, 91/109-1, 'Comte de Chambord', *R. borboniana* Desportes, 'Rose de Rescht' in Sweden and 91/107-1, 91/109-1, 'Chloris', *R. borboniana*,, 'Rose de Rescht' in Canada) selected genotypes in 1997 and 1998, respectively (data not shown). The genotypes for 1997 were selected according to their blackspot rating results in 1996 representing severely infected genotypes in the respective country. The same three genotypes were used for each country also in 1998 but now together with two additional ones (same for both countries). One of these represented a genotype that was severely infected in Sweden 1997 (*R. borboniana*) and the other one in Canada ('Rose de Rescht'). When the ratings passed a score of 9 for a majority of the selected indicator genotypes the whole trial was rated. At Morden this resulted in assessments in October in 1998 and September in 1997. At Balsgård however, this criterion was not fulfilled either of the 2 years. Therefore the assessments at this site were performed at the same date as in 1996. Different from blackspot, rust (*Phragmidium* spp.), powdery mildew (*Sphaerotheca pannosa* (Wallr.) Lév. var. *rosae* Wor.) and leaf spot (*Sphaceloma rosarum* [Pass.] Jenkins) were assessed on the whole plant on a scale of 0-3 (0=free of disease, 3=severe attacks) in September 1997 (Morden only) and in October 1998 (both sites).

Overall vigour of each plant was estimated in October 1997-1999 on a scale of 1-5 (1=very poor and small plant, 5=very vigorous and relatively large and full plant for the cultivar) at Balsgård. In Morden, vigour was assessed on a scale 1-4 (1=very poor and small plant, 4=very vigorous and relatively large and full plant for the cultivar) in September 1997 only. Height and width of the plants were measured at the end of the growing season at Balsgård in 1996, 1997, 1998 and in Morden in 1996.

Statistical analyses

The computer programs SYSTAT, version 5.2 (SYSTAT 1992), and SuperANOVA (SuperANOVA 1989) were used for statistical analyses.

Two analyses of variance were calculated on the assessments of winter injury. Only plants that were alive in the autumn before the winter of interest were included in these analyses. To analyse the variation in winter injury between the different genotypes, for each site and year separately, a two-way ANOVA test was applied on Least Squares Means for winter injury with the factors block and genotype. Genotypes for which all plants died during the winter of interest were excluded from the analysis. To compare the

Table 1 Winter injury (Least Squares Means (A)) and percentage surviving plants (B) in spring after the previous winter season for each of the genotypes at Balsgård from 1996-1999.

Rose group/section	**Accession**	**1996/1997**		**1997/1998**		**1998/1999**	
		A	**B**	**A**	**B**	**A**	**B**
Alba	Celestial (12)	5.8	100	8.0	100	6.2	100
	Chloris (12)	5.2	92	7.4	100	7.6	100
	Mme. Plantier (12)	3.0	67	6.9	100	7.4	100
Damask	Botzaris (12)	5.5	92	7.3	100	7.2	100
	Léda (12)	6.4	100	8.0	100	7.6	100
	Rose de Rescht (11)	3.1	54	6.8	100	4.9	100
Floribunda	Allgold (12)	0.2	8	-	0	-	-
	Astrid Lindgren (12)	0.2	8	3.0	100	-	-
	Chinatown (12)	-	0	-	-	-	-
	Korresia (=Sunsprite) (10)	-	0	-	-	-	-
Hybrid gallica	Complicata (12)	7.6	100	8.2	100	7.7	100
	Président de Sèze (7)	8.5	100	8.7	100	8.8	100
	Tuscany (12)	8.1	100	8.0	92	7.5	91
Gallicanae	*Rosa gallica officinalis* Thory (8)	5.2	88	8.7	100	8.7	100
	R. gallica versicolor L. (8)	7.2	100	8.5	100	8.8	100
Hybrid kordesii	Heidelberg (12)	-	0	-	-	-	-
Hybrid musk	Erfurt (12)	0.5	17	2.8	100	3.0	100
	Robin Hood (12)	0.2	8	-	0	-	-
	Sangerhausen (12)	0.7	25	3.2	100	1.9	67
Hybrid perpetual	Yolande d'Aragon (10)	-	0	-	-	-	-
Polyantha	Orange Triumph (12)	-	0	-	-	-	-
	The Fairy (12)	-	0	-	-	-	-
Portland	Comte de Chambord (12)	3.7	75	5.1	100	5.9	100
	Rose du Roi à Fleurs Pourpres (11)	2.0	36	2.1	75	2.3	100
Shrub	Elmshorn (12)	-	0	-	-	-	-
	Korlilub (=Lichtkönigin Lucia) (12)	1.0	33	2.5	100	2.0	50
Bourbon	*R. borboniana* Desportes (12)	2.0	50	1.9	83	2.3	80
Rosa	*R. carolina* L. (12)	8.8	100	8.8	100	8.7	100
	R. pendulina L. (12)	9.8	100	9.5	100	9.7	100
	R. pisocarpa Gray (12)	6.8	100	7.9	100	8.0	100
	R. rugosa Thunb. (12)	7.4	100	8.6	100	9.8	100
	R. woodsii var. *fendleri* Rehder (12)	8.2	100	8.5	100	9.1	100
Synstylae	*R. helenae* Rehder and Wilson (12)	5.8	92	7.4	100	7.9	100
	R. multiflora Thunb. ex Murray (12)	7.5	100	8.0	100	8.4	100
	R. wichurana var. *grandiflora* (12)	2.2	58	7.3	100	6.7	100
Subg. *Platyrhodon*	*R. roxburghii* Trattinnick (9)	3.6	67	6.4	100	7.4	100
Hybrid multiflora	Ghislaine de Féligonde (12)	-	0	-	-	-	-
	91/100-1 (12)	2.5	42	5.0	100	6.2	100
	91/100-5 (12)	4.0	75	4.7	89	5.6	100
	91/104-1 (12)	3.8	83	6.1	100	4.2	100
	91/107-1 (12)	3.0	75	4.8	100	5.6	100
	91/109-1 (12)	5.0	100	6.2	100	5.6	100
Mean		4.5	58	7.1	98	7.1	98
n		387	482	276	278	270	272
Std. Error		0.17		0.13		0.13	
F-statistics		27.3	***	20.0	***	26.0	***

Values do not include plants that died during the years preceding the winter of interest. Number of plants at the start of the trial are given in parenthesis. Accessions for which all plants were dead at the year of interest are not included in the analysis (-). Scores for winter injury (A): 0=dead plant to 10=no injury, good regrowth.
***, significant at $P<0.001$ by ANOVA.

two sites, each year separately, mean values for winter injury (all the genotypes taken together) were analysed with a nested analysis of variance including the factors site, genotype, genotype x site and block nested within site. Genotypes for which all plants died during the winter of interest at one site were excluded at both sites.

To analyse the variation in vigour between the different genotypes, for each site and year separately, two-way ANOVA tests were calculated with the factors block and genotype.

Pearson correlation values were calculated between the mean vigour ratings and mean winter injury scored after the following winter for each genotype to determine whether there was an association between vigour and winter injury. With the same method, the correlations between mean winter injury and mean height and width, respectively, of the genotypes were examined.

Two-way ANOVA tests with the factors block and genotype were calculated to analyse the variation in plant height and width, respectively, for each site and year separately. To study variation between the two sites in height and width respectively, all the genotypes taken together, for each year separately, were analysed with a nested analysis of variance including the factors site, genotype, genotype x site and block nested within site.

The blackspot assessment means for the different genotypes in each of the 4 blocks at each site were ranked and analysed with a two-way Friedman test (a nonparametric method was used instead of analysis of variance since the rating system did not produce normally distributed data) to study the variation in blackspot resistance between the different gentoypes in the trials. Each site was analysed separately.

With the purpose to reveal possible associations between amount of blackspot infection and other traits, Spearman rank correlation (*rs*) tests were calculated between the mean blackspot ratings for the genotypes for 1996-1998 on the one hand, and for 1) mean score (Least Square Means) for winter injury after the winters of 1996/97-1998/99 and for 2) vigour in 1997-1999 (in 1998 and 1999 Balsgård only), 3) height and width in 1996-1998 (only in 1996 in Morden) and 4) score values for rust, powdery mildew and leaf spot in 1997 and 1998 (only 1998 at Balsgård). This was performed for both sites separately.

Table 2 Winter injury (Least Squares Means (A)) and percentage surviving plants (B) in spring after the previous winter season for each of the genotypes in Morden from 1996-1999.

Rose group/section	Accession	1996/1997		1997/1998		1998/1999	
		A	B	A	B	A	B
Alba	Celestial (12)	4.2	92	5.6	100	5.8	100
	Chloris (12)	5.8	100	7.8	100	7.2	100
	Mme. Plantier (12)	4.3	100	4.8	100	4.8	100
Damask	Botzaris (12)	4.4	100	6.3	100	6.2	100
	Léda (12)	5.5	100	5.8	100	6.0	100
	Rose de Rescht (10)	3.5	100	3.9	100	4.5	100
Floribunda	Allgold (12)	1.4	67	1.6	62	1.2	40
	Astrid Lindgren (7)	2.6	86	3.2	100	4.2	100
	Chinatown (10)	2.4	90	2.5	100	2.0	67
	Korresia (10)	0.5	70	0.2	28	-	0
Hybrid gallica	Complicata (12)	4.2	100	4.8	100	5.7	100
	Président de Sèze (6)	3.7	83	5.4	100	5.2	100
	Tuscany (12)	5.2	100	8.1	100	6.8	100
Gallicanae	*Rosa gallica officinalis* (7)	4.3	100	5.9	100	5.0	100
	R. gallica versicolor (8)	3.8	100	5.8	100	4.9	100
Hybrid kordesii	Heidelberg (10)	0.9	60	1.8	100	3.0	100
Hybrid musk	Erfurt (11)	0.9	45	1.4	60	2.3	100
	Robin Hood (12)	2.2	67	2.3	100	3.2	100
	Sangerhausen (12)	3.7	100	3.7	92	3.7	100
Hybrid perpetual	Yolande d'Aragon (8)	1.5	50	3.9	100	3.7	75
Polyantha	Orange Triumph (12)	2.8	92	2.2	91	3.0	100
	The Fairy (12)	3.0	100	2.8	100	3.5	100
Portland	Comte de Chambord (2)	2.1	50	6.0	100	4.9	100
	Rose du Roi á Fleurs Pourpres (7)	3.5	100	3.4	100	3.7	100
Shrub	Elmshorn (11)	1.4	91	2.2	90	3.2	100
	Korlilub (12)	0.9	42	0.7	60	3.0	100
Bourbon	*R. borboniana* (12)	3.9	100	3.9	100	4.5	100
Rosa	*R. carolina* (12)	5.3	100	7.8	100	8.7	100
	R. pendulina (12)	6.4	100	10.0	100	9.9	100
	R. pisocarpa (12)	5.3	100	7.1	100	7.1	100
	R. rugosa (12)	4.7	100	7.5	100	8.6	100
	R. woodsii var. *fendleri* (12)	5.1	100	7.8	100	8.1	100
Synstylae	*R. helenae* (11)	3.4	100	3.4	100	4.6	100
	R. multiflora (12)	5.2	100	6.6	100	6.5	100
	R. wichurana var. *grandiflora* (12)	3.1	100	3.2	100	4.0	100
Subg. *Platyrhodon*	*R. roxburghii* (10)	1.3	50	3.4	80	3.8	75
Hybrid multiflora	Ghislaine de Féligonde (12)	1.8	83	2.4	90	3.9	100
	91/100-1 (11)	3.5	91	4.3	100	4.7	100
	91/100-5 (11)	4.2	100	3.8	100	3.9	100
	91/104-1 (12)	4.2	100	4.3	100	4.9	100
	91/107-1 (12)	4.3	100	3.6	100	4.0	100
	91/109-1 (12)	3.8	100	4.1	100	3.7	100
Mean		3.5	90	4.7	96	5.1	97
n		450	450	403	403	384	388
Std. Error		0.09		0.12		0.10	
F-statistics		22.9	***	52.2	***	53.4	***

Values do not include plants that died during the years preceding the winter of interest. Number of plants at the start of the trial are given in parenthesis. Accessions for which all plants were dead at the year of interest are not included in the analysis (-). Scores for winter injury (A): 0=dead plant to 10=no injury, good regrowth.
***, significant at $P<0.001$ by ANOVA.

RESULTS AND DISCUSSION

Weather during the trials

At Balsgård, the winter months of 1995/96 (November-March) were all colder than average, but nevertheless this winter was less detrimental to the plants in the trial compared to the following winter. In this winter, 1996/97, the average temperatures were slightly lower than the long term averages in December and January, but higher in February and March (**Table 3**). The winter of 1997/98 was warmer than average, whereas the last winter during the study period, 1998/99, was colder in the beginning but warmer than the averages in January, February and March.

The summer of 1996 was cool and wet at Balsgård compared to the summer of 1997, which was extraordinarily warm and long. In 1998 it was again cooler than the long term averages in June, July and August, but warmer in May, September and October (**Tables 3, 4**).

For Morden, cold temperatures in 1996/97 came early and although it was relatively cold there was good snow cover in early winter (**Tables 5, 6**). The next winter (1997/98) was close to average regarding temperature, except in December, whereas the precipitation was below average in September, November and December. In the last winter of the study (1998/99), the autumn was warmer than normal and the last months of 1998 were very dry with little precipitation except in October.

In the summer of 1996, temperature and precipitation were close to average in Morden whereas the growing season of 1997 had temperatures close to average but precipitation far above normal for the major part of the season (**Tables 5, 6**). In 1998, the spring was warmer than usual but summer temperatures were near normal. June was very wet followed by a drier than normal July, August and September.

Table 3 Climatic data from Kristianstad-Everöd airport (1995), Osby (1996) and Kristianstad (1997-1999), Sweden. Deviations are presented from long term averages for average monthly temperatures (°C) (A) and number of days with a minimum temperature below 0°C (B) measured during the trial period (1995-1999). Long term averages are based on the period 1961-1990.

Month	Average temperature	1995		1996		1997		1998		1999	
		A	B	A	B	A	B	A	B	A	B
January	-0.9			-0.7	25	-1.9	28	+2.8	14	+2.4	14
February	-0.8			-2.7	28	+2.4	9	+5.9	5	+0.3	17
March	1.7			-1.4	31	+1.8	16	+0.5	24	+1.6	13
April	5.8			+1.3	18	-0.4	15	+0.4	7	+2.0	5
May	11.0			-1.7	1	-1.1	2	+0.8	0	-1.0	3
June	15.2			-0.1	0	-0.1	0	-0.6	0		
July	16.6			-0.9	0	+1.7	0	-1.2	0		
August	16.1			+2.3	0	+4.0	0	-1.3	0		
September	12.5			-1.5	0	+1.1	0	+0.8	0		
October	8.6			+0.9	3	-2.2	10	+0.1	0		
November	4.1	-2.3	20	+0.6	13	-0.5	9	-3.2	18		
December	0.7	-4.6	28	-2.8	24	+1.7	9	-0.6	19		

The deviations from long term averages for average monthly temperatures in 1995 were calculated from long term averages from Kristianstad-Everöd airport and in 1996 from Osby (data not shown).

Table 4 Climatic data from Kristianstad-Everöd airport (1995), Osby (1996) and Kristianstad (1997-1999), Sweden. Deviations are presented from long term averages for average monthly precipitation (mm) (A) and maximum snow depth (cm) (B) measured during the trial period (1995-1999). Long term averages are based on the period 1961-1990.

Month	Average precipitation	1995		1996		1997		1998		1999	
		A	B	A	B	A	B	A	B	A	B
January	47			-52	18	-44	3	-10	11	+4	8
February	33			-3	16	+28	8	-3	6	+22	21
March	36			-32	8	-17	3	+14	5	+12	4
April	36			-22	8	-5	0	+26	0	+16	0
May	42			+75	0	+38	0	-7	0	+16	0
June	47			-24	0	+30	0	+66	0		
July	65			+5	0	-6	0	-1	0		
August	50			-21	0	-48	0	+12	0		
September	55			-8	0	-37	0	+10	0		
October	52			-30	0	+26	1	+58	0		
November	54	-18	-	+53	10	-14	0	-1	3		
December	46	-	-	-18	13	-10	0	+14	8		

The deviations from long term averages for average monthly precipitation in 1995 were calculated from long term averages from Kristianstad-Everöd airport and in 1996 from Osby (data not shown). Precipitation includes rain, snow and hail. Snow and hail are melted to water before measuring. No data was available for snow depth in November and December 1995 and for monthly precipitation in December 1995.

Vigour and height/width of plants

The *P*-values for variation between genotypes in vigour were highly significant ($P<0.001$) for both Balsgård and Morden in 1997 as well as for Balsgård in 1998 and 1999.

Mean values for height for the different genotypes, measured at the end of the growing season at each site in 1996, were slightly higher at Balsgård compared to in Morden, whereas the mean values for width were higher in Morden (**Table 8**). The *P*-values for variation between genotypes in both height and width were highly significant ($P<0.001$) for Balsgård all three years as well as for Morden in 1996 (only year of measurement). When the two sites were compared for height and width respectively in 1996, calculated as the mean for all genotypes taken together, with a nested analysis of variance (block nested within sites), significant differences could be observed between Balsgård and Morden for height (F=14.54, $P<0.001$) but not for width (F=0.05, $P=0.82$).

Winter survival

Looking at both sites, the genotypes that had the highest survival rates in the study belong to the groups alba, damask and hybrid gallica and species within the sections *Rosa* and *Synstylae*, which is not surprising as these groups/ sections are known to include many hardy cultivars (Gustavsson 1998). Four of the included breeding lines (91/100-5, 91/104-1, 91/107-1, 91/109-1) also showed a high survival rate. In Morden, 24 of the genotypes showed no plant loss at all during the trial, whereas only 12 retained all plants at the end of the study at Balsgård. The roses 'Léda' (damask), 'Complicata' (hybrid gallica), *R. gallica versicolor* (hybrid gallica), *R. carolina* L., *R. pendulina* L., *R. pisocarpa* Gray, *R. rugosa* Thunberg, *R. woodsii* var. *fendleri* Rehder, *R. multiflora* Thunberg ex Murray and 91/109-1 showed full survival after 3 winters both at Balsgård and in Morden and should therefore be favourable candidates for use as parents in both climates (**Tables 1, 2**). Tetraploids are found among the species *R. carolina* ($2n=2x=28$, rarely $2n=2x=14$), *R. pendulina* ($2n=2x=28$), and *R. multiflora* ($2n=2x=14$, $2n=2x=28$) which should aid in hybridization with the often tetraploid cultivars found among hybrid teas and floribundas.

Averaged over all years, 55% of the plants survived at Balsgård and 84% at Morden. At Balsgård, only 58% of the plants survived the winter of 1996/97, while 90% survived in Morden. After the winter of 1996/97, the most cold-sensitive genotypes appear to have been killed at each site since the survival rates were high at both sites for the subsequent winters, respectively. At Balsgård 98 and 98% of the plants remaining from the previous year (1997/98 and 1998/1999) survived, respectively, compared to 96 and 97% in Morden (**Tables 1, 2**). The largest differences in survival rates between the two sites were found within the groups floribunda, polyantha, hybrid musk, hybrid kordesii and hybrid perpetual. Especially the cultivars belonging to the floribunda, polyantha and the hybrid musk groups showed strikingly lower rates of survival at Balsgård. Cultivars in our study belonging to these groups are reported to show intermediate hardiness (Gustavsson 1998). The largest difference was observed for 'The Fairy' where all plants were killed at Balsgård in the winter of 1996/97, whereas all plants were alive in Morden at the end of the study in 1999.

Table 5 Climatic data from Environment Canada weather station at the Morden research station, Canada. Deviations from long term averages for averages monthly temperatures (°C) measured during the trial period 1995-1999. Long term averages are based on the period 1918-1999.

Month	Average temperature	1995	1996	1997	1998	1999
January	-16.1		-3.7	-1.3	+1.4	+0.5
February	-12.8		+0.8	+1.8	+8.5	+5.9
March	-5.8		-3.5	-2.1	+0.2	+4.2
April	4.1		-4.1	-3.7	+4.7	+2.7
May	11.9		-1.7	-2.3	+2.0	+1.0
June	17.3		+1.3	+2.2	-1.6	
July	20.3		-1.1	-0.5	-0.1	
August	19.2		+0.6	-0.1	+1.9	
September	13.3		+0.1	+2.2	+2.7	
October	6.6		-0.8	-0.8	+0.5	
November	-3.9	-4.8	-6.7	-0.5	+1.6	
December	-12.1	-2.3	-4.8	+8.0	+2.0	

Table 6 Climatic data from Environmental Canada weather station at the Morden research station, Canada. Deviations from long term averages for average monthly precipitation (mm) measured during the trial period 1995-1999. Long term averages are based on the period 1918-1999.

Month	Average precipitation	1995	1996	1997	1998	1999
January	23.2		-2.5	+16.6	+5.3	-3.3
February	21.4		-3.2	-10.7	+43.8	+7.6
March	29.4		+7.7	-13.0	-25.7	-10.1
April	36.5		-5.9	+70.1	+16.2	-1.5
May	62.2		+20.4	+33.2	+2.8	+164.6
June	80.7		-23.6	-10.7	+18.5	
July	75.9		+26.9	+68.4	-30.0	
August	64.6		-17.6	+0.9	-28.5	
September	51.5		+5.1	-33.4	-43.5	
October	36.8		-1.5	+45.2	+21.4	
November	32.3	+30.8	+28.9	-16.4	-	
December	22.9	+0.9	+20.1	-13.0	-6.8	

Precipitation includes rain, snow and hail. Snow and hail are melted to water before measuring. No data available for November 1998.

Only 4 genotypes had a higher survival rate at Balsgård compared to Morden (‘Celestial’, ‘Président de Sèze’, ‘Comte de Chambord’ and *R. roxburghii* Trattinnick).

The presence of an insulating snow cover is important for survival. The winter climate in Morden differs from that at Balsgård mainly by a much deeper snow cover and lower temperatures in autumn and winter (**Tables 3-6**). The summers are also warmer compared to at Balsgård. It could be noted that cultivars belonging to the floribunda, polyantha and hybrid musk groups, which showed a strikingly lower survival rate at Balsgård compared to Morden, often are rather short in stature; this means that they are covered by snow most winters in Morden but not at Balsgård. The winter and spring of 1996/97 was very detrimental to roses where Balsgård is situated in southern Sweden and severe damage was reported from several home gardens as well as from botanical gardens (Carlson-Nilsson 2000). Compared to the other winters in this study, the average temperatures at Balsgård in November–April were not extremely low in 1996/97; December, January and April were colder than the long term average, but the other months were warmer (**Tables 3, 4**). One reason for the low survival rate could instead be the combination of minimum temperatures below 0°C in January (28 days) and the almost complete lack of snow cover. Moreover, the fact that February and March in 1997 were warmer than long term averages, may have resulted in precocious dehardening of the plants. Since temperatures in April and May were slightly lower than the long term average, and even included days with minimum temperatures below 0°C, spring frost may have been responsible for some of the winter kill at Balsgård. According to Frankow-Lindberg and von Fircks (1998), lack of freezing tolerance *per se* does not seem to be the most limiting factor, but late de-hardening is essential in a climate where frequent spring frosts occur. Hou and Romo (1998) found an increased mortality in silver sagebrush seedlings (*Artemisis cana* Pursh.) after freezing in April on northern mixed prairies in Canada which indicated that the seedlings de-acclimated as temperatures rose and day length increased in spring. Instead, when the seedlings were fully acclimated in March, the seedling mortality after exposure to –39 and –45°C averaged only 5.6%.

Table 7 Transformation of blackspot assessment scores (F, L, M and S) to numeric values in 1997 and 1998.

Value	I	II
0	F	F
1	L	F
2	L	L
3	M	F
4	M	L
5	M	M
6	S	F
7	S	L
8	S	M
9	S	S

The plants are divided in two parts (I and II) which are rated individually. Each level was rated F=free of disease, L=light infection (trace to 20% of the leaf/stem area infected), M=moderate infection (21-50%) or S=(51-100%). For values 1, 3, 4, 6, 7, and 8 the order of the ratings is of no importance (e.g. L/F get the same values as F/L).

It also should be taken into consideration that the plants in our trial were grown on their own roots instead of being grafted. Roses on their own roots have an indefinite lifespan as there are no problems with the formation of suckers and rootstock/scion incompatibilities. However, plants from cuttings take longer to reach a saleable size and not all cultivars can be grown vigorously without a rootstock (Costa and Van de Pol 2003). Lundstad (1983) compared 9 climbing and 12 shrub rose cultivars grown on their own roots with the same cultivars bud-grafted on *R. canina* L. or *R. multiflora* rootstocks. The climbing roses had significantly better survival on their own roots in one year with a cool summer and particularly cold winter; in two other years there was no significant difference. The shrub roses had significantly better survival on their own roots in 2 out of 4 investigations. Generally, plants on their own roots did not grow as tall as plants on other rootstocks. Plants on *R. canina* rootstocks had a greater root system diameter, root mass and shoot weight than if grown on their own roots; even better results were obtained with *R. multiflora* rootstocks. In a trial performed by Mackay *et al.* (2008) 116 rose cultivars were evaluated under minimal input conditions in north-central Texas for 3 years. Own rooted cultivars performed significantly better than the grafted cultivars and had significantly better survival (P=0.001). For a climate like in Morden, roses grown on their own roots may be an important alternative to grafted ones, as the desired rose, and not the rootstock, re-grows after winter killing of the stems to the snow line or to the ground. In a climate like that at Balsgård, some cultivars may have been too weak to effectively grow on their own roots.

Winter injury

Significant differences (P<0.001) in the amount of winter injury were found between the Least Squares Mean values for the different genotypes at both Balsgård and Morden when the results for each of the three studied winters were analysed separately with ANOVA (**Tables 1, 2**). The results support our earlier suggestions that the included cultivars in the alba, damask and hybrid gallica groups together with the section *Rosa* species would be suitable for breeding programs for hardy roses. The genotype that was the least injured at both sites and after all three winters was *R. pendulina*. Other winter-hardy genotypes at Balsgård were *R. gallica officinalis* and 'Président de Sèze' in the hybrid gallica group together with *R. carolina*, *R. rugosa* and *R. woodsii* var. *fendleri* (**Table 1**). In Morden, the same species together with one cultivar from the hybrid gallica group, 'Tuscany', and two from the alba and damask groups were among the least injured roses (**Table 2**).

When the sites were compared for winter injury, calculated as the mean for all genotypes taken together, significant differences could be observed between Balsgård and Morden for each year (**Table 9**). However, in contrast to the results observed for survival rate, where Balsgård obtained the lowest results, this site had a smaller amount of winter injury after each winter on survivors. The difference in degree of winter injury between the sites was larger after the second and third winters. As described earlier, some geno-

Table 8 Mean height, H (cm), and width, W (cm), of genotypes at Balsgård (1996 to 1998) and Morden (1996), respectively, at the end of each growing season.

Rose group/section	**Accession**	**Balsgård**						**Morden**	
		1996		**1997**		**1998**		**1996**	
		H	**W**	**H**	**W**	**H**	**W**	**H**	**W**
Alba	Celestial	32.1	27.8	59.6	66.3	62.3	74.8	29.2	27.5
	Chloris	65.9	56.7	114.9	137.4	139.9	156.8	83.3	65.8
	Mme. Plantier	64.4	64.2	98.6	176.1	131.0	170.1	68.8	82.1
Damask	Botzaris	54.8	44.9	84.9	123.7	99.6	109.8	56.7	72.5
	Léda	50.1	53.8	66.2	100.7	82.4	112.2	50.8	77.9
	Rose de Rescht	26.9	25.7	43.0	49.8	54.7	60.0	38.5	34.5
Floribunda	Allgold	28.6	22.6	20.0	23.0	-	-	37.1	38.8
	Astrid Lindgren	39.1	41.4	54.0	54.0	41.0	35.0	47.1	48.6
	Chinatown	45.3	40.1	-	-	-	-	34.0	36.0
	Korresia	18.1	14.6	-	-	-	-	26.5	26.0
Hybrid gallica	Complicata	82.6	109.7	105.1	176.1	135.6	208.3	65.4	93.8
	Président de Sèze	48.3	33.7	76.7	80.0	83.1	111.7	39.2	45.8
	Tuscany	38.1	26.2	63.8	66.1	68.7	83.4	47.9	40.8
Gallicanae	*Rosa gallica officinalis*	29.3	25.1	66.1	84.8	77.0	99.7	33.4	39.3
	R. gallica versicolor	35.0	36.5	77.2	85.6	81.1	110.4	40.0	42.5
Hybrid kordesii	Heidelberg	26.8	34.2	-	-	-	-	32.0	35.0
Hybrid musk	Erfurt	32.7	54.8	59.5	114.5	52.0	47.0	39.5	91.8
	Robin Hood	43.6	72.6	30.0	45.0	-	-	50.8	86.7
	Sangerhausen	45.3	30.5	40.7	29.0	41.0	20.0	52.1	47.1
Hybrid perpetual	Yolande d'Aragon	36.6	21.1	-	-	-	-	43.8	40.0
Polyantha	Orange Triumph	41.6	52.2	-	-	-	-	37.9	56.7
	The Fairy	37.0	66.2	-	-	-	-	32.1	61.2
Portland	Comte de Chambord	27.7	19.9	29.9	24.9	36.1	30.2	20.0	15.0
	Rose du Roi à Fleurs Pourpres	22.4	13.3	37.8	27.5	34.0	22.3	34.3	30.7
Shrub	Elmshorn	55.7	58.2	-	-	-	-	49.1	58.6
	Korlilub	38.8	34.0	42.5	33.0	41.0	25.2	47.1	42.9
Bourbon	*R. borboniana*	28.7	24.5	26.0	25.2	27.0	17.6	43.3	52.9
Rosa	*R. carolina*	63.8	87.5	120.9	158.8	159.4	182.9	48.3	75.0
	R. pendulina	83.1	109.7	140.1	152.6	177.7	180.4	60.0	55.4
	R. pisocarpa	129.0	131.6	171.3	227.3	241.1	235.8	57.9	80.4
	R. rugosa	39.6	54.9	57.0	107.6	91.6	138.1	39.2	49.2
	R. woodsii var *fendleri*	109.1	146.1	142.5	235.1	178.3	234.4	47.1	87.5
Synstylae	*R. helenae*	57.3	138.4	87.5	348.6	132.1	376.8	56.4	148.6
	R. multiflora	96.4	222.9	95.1	284.9	153.6	378.3	67.1	156.2
	R. wichurana var. *grandiflora*	22.2	243.6	24.1	550.1	49.4	464.0	27.1	209.2
Subg. *Platyrhodon*	*R. roxburghii*	24.6	31.6	75.2	79.2	64.3	77.7	21.0	30.0
Hybrid multiflora	Ghislaine de Féligonde	46.6	69.0	-	-	-	-	64.2	113.8
	91/100-1	37.8	33.6	55.0	57.0	73.0	66.6	34.0	36.5
	91/100-5	32.2	27.8	39.0	40.1	53.5	45.1	31.8	28.6
	91/104-1	46.4	38.0	60.2	54.3	73.6	66.2	30.0	29.2
	91/107-1	29.8	39.8	32.6	44.7	47.2	53.2	37.7	43.6
	91/109-1	36.7	35.4	51.4	45.7	45.8	45.6	33.8	37.1
Mean		47.2	61.7	79.1	132.4	101.7	146.9	44.9	64.2
n		477	477	276	276	271	271	448	448
Std. Error		1.27	2.50	2.59	6.82	3.49	6.97	0.84	2.05

Table 9 Nested analyses of variances, calculated for mean winter injuries (block nested within site) for the winters of 1996/97 to 1998/99.

Site	Mean winter injuries (0-10)		
	1996/97	1997/98	1998/99
Balsgård	4.49	7.11	7.14
Morden	3.91	5.34	5.65
F-value	41.18	133.84	161.82
P	<0.001	<0.001	<0.001

Scale for winter injury; 0=dead plant to 10=no injury and good plant growth.

types with intermediate hardiness seem to have a higher survival rate in Morden compared to at Balsgård. Nevertheless, some of them do obtain rather severe winter injury because of the cold climate in Morden which may be related to the presence or absence of a snow cover. The snow cover increases the survival rate as the roots and the part of the plant that is covered is protected. The part of the stems that are above the snow line may however be seriously damaged by cold from the typically low temperatures experienced at Morden. With the absent or very thin snow cover existing at Balsgård the plants that survived were quite winter hardy and consequently did not suffer much from cold damage either. The importance of snow cover is shown by a field study in Minnesota, USA, where winter injury observations for three winters were compared for seven different rose cultivars (Zuzek *et al*. 1995). One year the snowcover was minimal or absent and many of the cultivars which otherwise typically exhibit the "snowline" pattern of hardiness died back to the ground that winter. In this trial this dieback was very common among albas, bourbons, centifolias, hybrid gallicas, hybrid perpetuals and moss roses as well as cultivars from the floribunda, hybrid musk, hybrid perpetual, hybrid rugosa, hybrid suffulta and hybrid kordesii groups.

The Pearson correlation tests between vigour and winter injury yielded highly significant values, r=0.903 (P<0.001) for Balsgård after the winter of 1997/98 and r=0.808 (P<0.001) after the winter of 1998/99. Large and vigorous plants suffered less from winter injury the following winter compared to small and weak plants. At Morden the correlation was somewhat lower (r=0.471, P=0.002) when the vigour ratings for the growing season of 1997 were tested against the amount of winter injury after the winter of 1997/98.

Pearson correlation tests calculated on mean plant height for the different genotypes at the end of the growing season and winter injury obtained in the following winter indicate that among the genotypes included in this trial, taller plants suffer less from winter injury than shorter ones. At Balsgård, correlations varied between r=0.529 and r=0.657 (P<0.001 for all three years), whereas the correlation in Morden was lower (r=0.444, P=0.003). Significant correlations were also found between the width of the plants and the amount of winter injury (r=0.311 to r=0.549, P<0.001) at Balsgård. However, the single correlation estimated in Morden between width and winter injury was not significant (r=0.159, P=0.315). This close association between vigour, height/width and winter injury was not unexpected since the groups/sections that have the largest mean values for height and width (**Table 8**) are known to include several genotypes with good winter hardiness, like alba, damask and hybrid gallica together with species within the section *Rosa*. The strong tendency for larger growing roses displaying less winter injury may be related to the fact that these larger roses were non-recurrent blooming genotypes. Growing points produced after the initial flowering generally continue to elongate as they do not terminate in additional flowers during the rest of the growing season. In addition, more energy reserves coming fall may be available in these roses for acclimation rather than being invested in continued flower production.

The mean value for width calculated across all genotypes, did not differ significantly between the two sites. By contrast, a significant difference was found between the sites for height. Analysing each genotype separately, it is obvious that height and width are larger at Balsgård compared to Morden when looking at most of the genotypes in the group of species (except *R. borboniana*) and the *R. multiflora* hybrids (height) (**Table 8**). It is most obvious for *R. pisocarpa* and *R. woodsii* var. *fendleri*. In the other groups and sections, only a few genotypes were taller/broader at Balsgård. This indicates that the growing conditions at Balsgård somehow were more favourable for the species and *R. multiflora* hybrids, which grew more rapidly, compared to in Morden. On the contrary, the conditions in Morden seemed more suitable for most of the cultivars for their first growing season. Since no assessments of height and width were made in Morden in the two following growing seasons, it is not possible to say if this trend continued after the first season. It is also impossible to ascertain to what degree the fertilizer (applied only at Balsgård) had an effect on the growth rates. However, the plants at Balsgård were overall smaller, except for species, and it seems unlikely that only species roses would have responded to the addition of fertilizer at Balsgård.

Blackspot

The two-way Friedman test, calculated on the block mean values of the assessments of blackspot infection during each growing season, showed highly significant differences among the genotypes included in the analysis each year and at both sites (Balsgård: P<0.001, P=0.035 and P=0.001 for 1996, 1997 and 1998, respectively; Morden: P<0.001 for all 3 years). Although the most severely infected genotypes varied between years, *R. borboniana*, 'Allgold', 'Comte de Chambord', 'Heidelberg' and 'Sangerhausen' showed high values at both sites (**Table 10**). The hybrid gallica group together with the species roses were the least infected groups at both sites. Since these groups also contained some of the genotypes that were the least damaged by winter injury, they appear to contain promising germplasm for use in breeding programs for hardy and disease resistant ornamental roses. It should however be noted that not all cultivars in the hybrid gallica group had the same tolerance to blackspot. For example, 'Complicata' was comparatively poor at both sites (**Table 10**).

In the growing season of 1996, the mean value for blackspot infection across all genotypes was 4.0 at Balsgård and 4.3 in Morden (**Table 10**). Although the mean values did not differ much, their distribution was somewhat different at the two sites. At Balsgård, several genotypes seemed to have a fairly low infection rate with mean values between 2 and 4 in 1996, whereas only a few were severely attacked. In Morden, more genotypes had a higher mean infection rate in 1996. In the two following years, the amount of infection decreased at Balsgård (0.6 and 0.8) whereas it increased in Morden (4.9 and 4.4) (**Table 10**). The distribution of the mean values for blackspot infection for the different genotypes was rather similar in 1997 and 1998 at Balsgård with most of the genotypes being non-infected or having very low infection rates. The rest of the genotypes were evenly distributed across the scale. In Morden, the distribution was fairly even in 1997, except for a rather high number of genotypes with very high infection rates. Finally, in 1998, the mean values were even more evenly distributed. Eight and 10, respectively, of the genotypes were not included in the results from Balsgård in 1997 and 1998, primarily because of severe winter injury. If the same genotypes however, were excluded from the calculations of the Morden material, the mean values only changed to 4.7 and 4.3 from 4.9 and 4.4.

It should also be noted that in 1996, the fungal disease leaf spot was observed in the fields at Balsgård for the first time to the author´s knowledge. Unfortunately, some infections caused by this disease were initially misinterpreted as blackspot during this year which may explain part of the higher total mean value at Balsgård in 1996 for blackspot compared to 1997 and 1998. Another reason for the higher total mean value in 1996 could be that *D. rosae* is a predominantly water-distributed fungus with a limited range of dispersal and the disease follows a developmental pattern which is dependent on accumulating inocula (Saunders 1966). Saunders (1970) reports large differences between degrees of infections on a given cultivar in different years because of factors like climatic conditions (amount of preciptiation and daily temperatures) and physiological status of the host plants. Development of the fungus during the growing season depends on the triggering of accumulated inocula in late summer by heavy rainfall coincidental with an average daily temperature above 14°C (Saunders 1966). The summer weather in 1997 differed from that in 1996; there was less late summer rainfall in August and September in 1997 compared to 1996. Moreover, July, August and September were warmer in 1997, and September was warmer in 1998 compared to 1996. The warmer and drier weather during the latter part of the growing season in 1997 and 1998 may have led to less blackspot infection compared to 1996. Furthermore, as mentioned above, several genotypes died at Balsgård primarily because of severe winter injury. Some of them, like 'Allgold', 'Heidelberg' and 'Yolande d'Aragon' were severely infected by blackspot in 1996. Several important sources of inoculum thus disappeared with the loss of these genotypes.

The higher infection rates in Morden all three years of the study were somewhat unexpected as the differences in climate between the sites and the preferences of the fungus suggests a more favourable environment for the pathogen at Balsgård with its humid summers and mild winters. The higher infection rates in Morden were especially striking for the *R. multiflora* hybrids; these genotypes were more or less free from infection in 1997 and 1998 at Balsgård, whereas they were clearly infected all three years in Morden. According to von Malek and Debener (1998), 91/100-5 displays a broad resistance to all blackspot races tested so far and was at the time of this study used as a donor to introduce resistance into the genetic background of cultivated roses in model breeding programmes in Ahrensburg, Germany. von Malek and Debener (1998) also report the detection of a single dominant resistance locus in 91/100-5. One possible explanation to the discrepancy in blackspot infection values between the sites is the existence of different isolates or races of the fungus. Considerable genetic differentiation between single spore isolates collected at different locations has been demonstrated by Werlemark *et al.* (2006). Isolates

Table 10 Mean values for blackspot infection for each genotype at Balsgård and Morden, respectively, from 1996 to 1998.

Rose group/section	**Accession**	**Balsgård**			**Morden**		
		1996	**1997**	**1998**	**1996**	**1997**	**1998**
Alba	Celestial	2.8	0.1	1.4	2.4	4.7	4.9
	Chloris	3.3	0.4	0.0	5.8	8.3	2.5
	Mme. Plantier	4.4	0.2	0.2	2.6	2.7	1.7
Damask	Botzaris	3.1	0.2	0.4	4.8	5.0	3.7
	Léda	3.8	0.6	0.4	4.2	5.5	4.5
	Rose de Rescht	6.6	5.0	5.2	4.0	8.0	7.6
Floribunda	Allgold	7.8	8.0	-	7.2	8.4	3.8
	Astrid Lindgren	5.5	0.0	2.0	3.8	6.5	5.5
	Chinatown	3.6	-	-	5.1	7.4	4.1
	Korresia	5.0	-	-	4.1	1.2	5.0
Hybrid gallica	Complicata	3.5	0.4	1.2	5.6	4.2	4.0
	Président de Sèze	1.7	0.0	0.0	1.0	2.6	2.6
	Tuscany	2.5	0.2	0.0	3.2	2.2	4.2
Gallicanae	*Rosa gallica officinalis*	2.2	0.0	0.1	1.7	0.6	4.7
	R. gallica versicolor	2.6	0.1	0.1	1.9	1.8	3.4
Hybrid kordesii	Heidelberg	8.9	-	-	8.3	8.5	4.8
Hybrid musk	Erfurt	6.3	0.5	1.0	5.3	7.6	3.7
	Robin Hood	3.3	0.0	-	5.2	6.1	4.6
	Sangerhausen	6.6	6.7	2.0	6.8	8.9	8.2
Hybrid perpetual	Yolande d'Aragon	7.0	-	-	4.9	6.0	3.5
Polyantha	Orange Triumph	5.6	-	-	7.9	8.4	8.0
	The Fairy	4.8	-	-	4.9	3.1	3.3
Portland	Comte de Chambord	5.9	6.2	5.6	3.0	9.0	9.0
	Rose du Roi à Fleurs Pourpres	5.4	0.5	0.7	1.3	5.1	4.7
Shrub	Elmshorn	4.0	-	-	7.0	7.8	6.9
	Korlilub	5.1	0.5	2.0	4.8	6.0	2.0
Bourbon	*R. borboniana*	8.5	4.6	7.4	5.7	8.8	7.7
Rosa	*R. carolina*	1.6	0.0	0.0	4.8	1.8	2.2
	R. pendulina	2.4	0.0	0.0	3.6	7.5	5.9
	R. pisocarpa	2.5	0.7	1.4	2.0	7.2	4.0
	R. rugosa	0.3	0.0	0.0	0.0	0.0	0.3
	R. woodsii var. *fendleri*	1.1	0.0	0.4	3.2	2.5	1.8
Synstylae	*R. helenae*	2.7	0.1	0.4	3.4	1.0	2.7
	R. multiflora	3.0	0.0	0.3	3.8	1.8	2.0
	R. wichurana var. *grandiflora*	3.8	0.4	0.0	4.2	1.5	2.1
Subg. *Platyrhodon*	*R. roxburghii*	0.6	0.0	0.0	0.0	0.6	1.7
Hybrid multiflora	Ghislaine de Féligonde	2.2	-	-	3.2	1.9	2.8
	91/100-1	3.1	0.0	0.0	2.0	2.4	3.9
	91/100-5	2.8	0.0	0.4	6.2	9.0	7.4
	91/104-1	3.9	0.0	0.0	1.6	0.3	5.4
	91/107-1	3.0	0.0	0.2	8.7	8.9	9.0
	91/109-1	2.9	0.0	0.0	6.0	8.1	7.4
Mean		4.0	0.6	0.8	4.3	4.9	4.4
n		454	267	260	448	397	371
Std. Error		0.12	0.12	0.12	0.12	0.17	0.15

Scores for blackspot infection; 0=no infection to 9=severe infection.

collected from locations as close as 30 km showed substantial differentiation in RAPD patterns, and these differences then increased with increasing geographic distances. However, it remains to be studied whether there is a corresponding differentiation in pathogenicity.

Blackspot, vigour and height/width

In two out of three years of observation (1996 and 1998), significant negative correlations were obtained with Spearman rank correlation, at Balsgård for degree of blackspot infection and height/width of the plant at the end of the growing season (*rs*=-0.383, *P*<0.05 for height in 1996, *rs*=-0.392, *P*<0.05 for height in 1998, *rs*=-0.343, *P*<0.05 for width in 1996, *rs*=-0.420, *P*<0.05 for width in 1998). Corresponding correlations could not be found in Morden the only year height and width measurements were conducted (1996).

With the same test, degree of blackspot infection was negatively correlated to vigour of the plants at the end of the growing season the following year. However the correlation was significant only at Balsgård in 1996/97 (*rs*=-0.696, *P*<0.001) and 1998/99 (*rs*=-0.388, *P*<0.05). However, it should be noted that vigour was only assessed in Morden in 1997. A significant negative correlation was also noted for vigour and degree of blackspot the following year for both sites in 1998/99 (*rs*=-0.419, *P*<0.01 for Balsgård and *rs*=-0.488, *P*<0.01 for Morden).

Blackspot and other diseases

Among the other diseases (rust, powdery mildew and leaf spot) (assessed in 1998 at Balsgård and in 1997 and 1998 in Morden), rust was uncommon and occurred only at low levels at both sites, except in Morden in 1998 when infections were observed on 76% of the genotypes (mean infection across genotypes = 0.5) (**Tables 11, 12**).

The mean level of powdery mildew infection did not differ much between the sites in 1998 (0.2 at Balsgård and 0.1 in Morden; no assessments performed in 1997 at Balsgård) (**Tables 11, 12**).

At both sites, leaf spot was the disease that caused the highest amount of infection when overall means were compared. At Balsgård, this disease appears to become increasingly common on field grown roses. It does not cause the drop of leaves like blackspot does, but is cosmetically devastating to the plants. In 1998 the mean level of infection of leaf spot was twice as high at Balsgård (1.8) compared to

Table 11 Mean values for leaf spot (LS), powdery mildew (PM) and rust infection (R) for each genotype at Balsgård in 1998.

Rose group/section	**Accession**	**1998**		
		LS	**PM**	**R**
Alba	Celestial (12)	1.3	0.0	0.0
	Chloris (12)	1.4	0.0	0.1
	Mme. Plantier (12)	1.6	0.0	0.0
Damask	Botzaris (12)	1.9	0.0	0.0
	Léda (12)	1.6	0.0	0.0
	Rose de Rescht (11)	1.7	0.2	0.0
Floribunda	Allgold (12)	-	-	-
	Astrid Lindgren (12)	2.0	0.0	0.0
	Chinatown (12)	-	-	-
	Korresia (10)	-	-	-
Hybrid gallica	Complicata (12)	2.2	0.0	0.7
	Président de Sèze (7)	1.6	0.0	0.0
	Tuscany (12)	2.5	0.1	0.0
Gallicanae	*Rosa gallica officinalis* (8)	1.8	0.4	0.0
	R. gallica versicolor (8)	2.0	0.9	0.0
Hybrid kordesii	Heidelberg (12)	-	-	-
Hybrid musk	Erfurt (12)	1.0	0.0	0.0
	Robin Hood (12)	-	-	-
	Sangerhausen (12)	2.0	0.0	0.0
Hybrid perpetual	Yolande d'Aragon (10)	-	-	-
Polyantha	Orange Triumph (12)	-	-	-
	The Fairy (12)	-	-	-
Portland	Comte de Chambord (12)	1.6	0.0	0.0
	Rose du Roi à Fleurs Pourpres (11)	2.7	0.0	0.0
Shrub	Elmshorn (12)	-	-	-
	Korlilub (12)	2.8	0.0	0.0
Bourbon	*R. borboniana* (12)	1.2	0.0	0.0
Rosa	*R. carolina* (12)	1.7	0.2	0.2
	R. pendulina (12)	1.8	2.2	0.0
	R. pisocarpa (12)	1.0	1.0	0.0
	R. rugosa (12)	1.1	0.0	0.0
	R. woodsii var. *fendleri* (12)	1.4	0.0	0.0
Synstylae	*R. helenae* (12)	1.6	0.2	0.0
	R. multiflora (12)	2.3	0.8	0.0
	R. wichurana var. *grandiflora* (12)	1.3	0.0	0.0
Subg. *Platyrhodon*	*R. roxburghii* (9)	1.5	0.0	0.0
Hybrid multiflora	Ghislaine de Féligonde (12)	-	-	-
	91/100-1 (12)	3.0	0.0	0.0
	91/100-5 (12)	2.4	0.0	0.0
	91/104-1 (12)	3.0	0.0	0.0
	91/107-1 (12)	1.8	0.0	0.0
	91/109-1 (12)	2.4	0.0	0.0
Mean		1.8	0.2	0.04
n		271	271	271
Std. Error		0.04	0.03	0.01

Scores for infection; 0=no infection to 3=severe infection. Number of plants at the start of the trial are given in parenthesis.

Table 12 Mean values for leaf spot (LS), powdery mildew (PM) and rust infection (R) for each genotype at Morden in 1997 and 1998.

Rose group/section	Accession	1997			1998		
		LS	PM	R	LS	PM	R
Alba	Celestial (12)	1.0	0.3	0.0	0.6	0.0	1.1
	Chloris (12)	1.1	0.0	0.0	1.1	0.0	2.2
	Mme. Plantier (12)	0.8	0.2	0.0	1.1	0.0	0.5
Damask	Botzaris (12)	1.6	0.0	0.0	0.9	0.2	0.8
	Léda (12)	0.8	0.2	0.0	0.8	0.4	0.8
	Rose de Rescht (10)	1.0	0.0	0.0	0.6	0.1	0.6
Floribunda	Allgold (12)	0.0	0.0	0.0	0.4	0.0	0.0
	Astrid Lindgren (7)	0.7	0.0	0.0	1.0	0.0	0.3
	Chinatown (10)	0.4	0.0	0.0	0.6	0.3	0.4
	Korresia (10)	1.0	0.0	0.8	2.0	0.0	1.0
Hybrid gallica	Complicata (12)	1.1	0.0	0.0	1.0	0.2	0.5
	Président de Sèze (6)	1.0	0.0	0.0	0.4	0.8	1.0
	Tuscany (12)	1.2	0.0	0.0	1.2	0.4	0.5
Gallicanae	*Rosa gallica officinalis* (7)	1.0	0.3	0.0	0.6	0.1	0.8
	R. gallica versicolor (8)	1.1	0.1	0.0	1.2	0.4	1.4
Hybrid kordesii	Heidelberg (10)	0.0	0.0	0.0	1.0	0.0	0.0
Hybrid musk	Erfurt (11)	0.2	0.0	0.0	0.7	0.0	1.0
	Robin Hood (12)	1.0	0.0	0.0	1.1	0.0	0.8
	Sangerhausen (12)	0.0	0.0	0.0	0.3	0.0	0.0
Hybrid perpetual	Yolande d'Aragon (8)	1.0	0.0	0.0	0.5	0.2	1.5
Polyantha	Orange Triumph (12)	0.1	0.0	0.0	0.4	0.0	0.0
	The Fairy (12)	0.8	0.2	0.0	1.4	0.0	0.8
Portland	Comte de Chambord (2)	1.0	0.0	0.0	0.0	0.0	0.0
	Rose du Roi à Fleurs Pourpres (7)	0.8	0.0	0.0	1.0	0.4	1.4
Shrub	Elmshorn (11)	0.7	0.0	0.0	0.9	0.0	0.0
	Korlilub (12)	0.0	0.0	0.0	1.3	0.0	0.0
Bourbon	*R. borboniana* (12)	0.4	0.0	0.0	0.4	0.0	0.1
Rosa	*R. carolina* (12)	1.2	0.8	0.0	1.1	0.8	0.2
	R. pendulina (12)	1.2	0.8	0.0	1.1	0.0	0.3
	R. pisocarpa (12)	1.1	0.0	0.0	0.8	0.0	0.4
	R. rugosa (12)	0.1	0.0	0.0	0.2	0.0	0.2
	R. woodsii var. *fendleri* (12)	1.3	0.2	0.0	2.4	0.0	0.5
Synstylae	*R. helenae* (11)	1.0	0.0	0.0	0.8	0.3	0.5
	R. multiflora (12)	1.1	0.0	0.0	1.6	0.0	0.3
	R. wichurana var. *grandiflora* (12)	0.9	0.0	0.0	0.4	0.1	0.2
Subg. *Platyrhodon*	*R. roxburghii* (10)	0.6	0.0	0.0	0.3	0.0	1.0
Hybrid multiflora	Ghislaine de Féligonde (12)	0.9	0.5	0.0	1.1	0.9	0.1
	91/100-1 (11)	0.9	0.0	0.0	1.3	0.2	0.6
	91/100-5 (11)	0.0	0.0	0.0	0.2	0.0	0.0
	91/104-1 (12)	0.9	0.0	0.0	1.7	0.0	0.5
	91/107-1 (12)	0.1	0.0	0.0	0.4	0.0	0.0
	91/109-1 (12)	1.2	0.0	0.1	1.2	0.0	0.0
Mean		0.8	0.1	0.01	0.9	0.1	0.5
n		396	397	397	372	372	372
Std. Error		0.03	0.02	0.005	0.04	0.02	0.04

Scores for infection; 0=no infection to 3=severe infection. Number of plants at the start of the trial are given in parenthesis.

in Morden (0.9) (**Tables 11, 12**). In 1997, only 5 genotypes, were completely free from infections in Morden. Two of them were 'Allgold' and 'Sangerhausen'. Interestingly, these two cultivars were among the most severely blackspot infected genotypes in the same year. The situation was the same for the cultivar 'Comte de Chambord' which was the only genotype free from leaf spot infection in Morden in 1998. No genotype was free from infection at Balsgård in 1998. The Spearman rank correlation tests between blackspot infection rates and leaf spot infection rates for all genotypes in the trial suggest that blackspot infection and leaf spot infection in the same year are negatively correlated, although the only significant result was obtained for Morden in 1997 (rs=-0.348, P<0.05). In Morden, there were also significant negative correlations between blackspot infection and leaf spot infection in the next year (rs=-0.337, P<0.05 for 1996/1997, rs=-0.369, P<0.05 for 1997/1998). In conclusion, a rose plant that has become severely infected by blackspot, appears to evade infection by other fungal diseases like leaf spot not only during the same growing season but also during the coming season. This suggests competition between the different fungi. Since the amount of blackspot infection was much lower at Balsgård compared to Morden in 1997 and 1998, this competition is not as severe at Balsgård which may explain the absence of significant correlations between the diseases at that site.

Blackspot and winter injury

Mackay *et al.* (2008) found that blackspot was closely correlated to overall performance and final vigour in a study where 116 rose cultivars were evaluated for 3 years. McClellan (1953) suggested that blackspot is indirectly responsible for much of the winter injury in roses. This was noticed already in the preliminary results after the winter 1996/97 when plants with severe blackspot infection in the summer of 1996 appeared to suffer more winter damage during the winter of 1996/97 (Carlson-Nilsson and Davidson 2000). These preliminary results were further confirmed in the full study as significant negative correlations were observed at Balsgård between amount of blackspot infection and degree of winter injury during the following winter when analysed with Spearman rank correlation test (rs=-0.665, P<0.001 for 1996/1997; rs=-0.354, P<0.05 for 1997/1998; rs=-0.502, P<0.01 for 1998/1999). A corresponding correlation, however, was not found in Morden possibly because the climate at Balsgård was more detrimental to roses that have been severely infected by blackspot. Plants that have been prematurely defoliated by blackspot often respond with increased vegetative growth in late summer and autumn. This new growth may not mature properly before the arrival of cold weather. The milder temperatures late in autumn at Balsgård thus favour the continued growth of the infected plants. When the cold temperatures finally arrive, plants are not sufficiently acclimated and have depleted energy reserves that may otherwise have been devoted to overwintering. In Morden, autumn starts earlier and the plants stop growing before producing as much new growth as at Balsgård. The common lack of a sufficient snow cover at Balsgård may also be of importance.

Significant negative correlations were also obtained at Balsgård between blackspot infection rates and degree of injury contracted in the preceding winter (rs=-0.347, P<0.05 for 1997; rs=-0.471, P<0.01 for 1998). This means that a plant with severe winter injury was likely to obtain a higher degree of blackspot infection in the summer later that same year. Again, these correlations were not significant in Morden.

ACKNOWLEDGEMENTS

Valuable advice on the statistical analyses by Jan-Eric Englund is gratefully acknowledged. The authors would also like to acknowledge the input of field personnel and the technical input of L. Dyck. The project was funded by the former Swedish Research Council for Forestry and Agriculture.

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