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Desiccation Tolerance in Bare-rooted Apple Trees Prior to Transplanting[1]

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Abstract

Ten types of apple (*Malus domestica* L.) trees (six different scions on M.7 rootstock and four 'Red Delicious' scions on M.7, MM.111, MM.106 and seedling rootstocks) were subjected to air drying for periods of 0 to 48 hr with or without 3 months of cold storage at 0°C (32°F). The kinetics of water loss during drying treatment and the transplanting survival and regrowth vigor were recorded. Both the scions and rootstocks influenced the tolerance of apple trees to desiccation stress. Among the plant materials tested, 'Red Delicious' on MM.111 rootstock had the highest level of tolerance to desiccation. Three months of cold storage at 0°C (32°F) resulted in the considerable loss of tissue water, but the grafted trees survived if no further desiccation occurred prior to planting. Only 'Red Delicious'/MM.111 tolerated desiccation from the combination of three months of cold storage followed by a 48 hr exposure to air drying, while other scion/rootstock compound systems seldom survived. The analyses of water loss from apple trees indicated that the loss did not follow a simple first order reaction. However, there were two distinct first order water loss slopes suggesting that the loss was from two fractions of water inside plant tissues. One fraction of tissue lost water at a faster rate than the following second fraction which was slowly released from the plant tissues. There was no difference in the critical water content and rate of water loss between the tolerant trees, (i.e., 'Red Delicious' on MM.111) and the others. Therefore it is suggested that trees on MM.111 are more tolerant to desiccation because of the tolerance to water loss in the tissue.

Index words: *Malus domestica*, postharvest storage, transplanting survival, drying stress

Significance to the Nursery Industry

Sensitivity to desiccation stress during nursery handling is one of the main reasons for poor regrowth of bare-rooted nursery stocks. Plants subjected to desiccation during any phase of nursery production will have reduced growth potential and poor quality. This study analyzed the effect of desiccation tolerance on various scion/rootstock combinations of bare-rooted apple trees. It appears that both the scion and rootstock influence the post-stress regrowth and survival. Scions grafted on MM.111 rootstocks had the highest level of tolerance to desiccation. The results also suggested that trees on MM.111 are more tolerant to desiccation because of the tolerance to water loss in the tissue.

Introduction

It is common nursery production practice to dig nursery grown fruit trees in the fall/winter season and stored bare-rooted in cold storage or heeled in sawdust until ready for shipping or planting. Desiccation stress is one of the factors impacting the survival and performance of these cold stored bare-root trees.

Desiccation stress during post harvest handling is a major problem in some plant species (1, 4, 6). Woody plants lose water immediately when lifted from the ground, and a prolonged period of exposure to the air during post harvest handling and cold storage results in decreased survival and growth rates (1, 3, 6). Desiccation damage could not be reversed by rewetting once dried below a critical level (4, 5). Unfortunately, desiccated deciduous and evergreen plants are not easily distinguishable visually (1, 4–7). There is a wide variation among plant species (1, 3–5, 7), growth stage (3, 6), and plant tissue (4) in desiccation tolerance. Because there is no reliable method for measuring the desiccation tolerance of shoot and root tissue separately, the role of roots in the survival after desiccation is unclear.

In apples, various combinations of scion and rootstocks are widely used. The availability of the wide spectra of scion/rootstock combinations make it possible to study the influence of shoots and roots on the stress tolerance of the bare-rooted trees.

The objectives of this study were to compare the desiccation tolerance among apple trees of various scion/rootstock combinations and to analyze the kinetics of water loss from plant tissues in relation to their desiccation tolerances.

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Materials and Methods

Bare-rooted apple trees with several scion/rootstock combinations were used in this study (Table 1). The two-year-old nursery trees, dug in January 1989, were obtained from Carlton Plants, Inc. Dayton, Oregon.

Each scion/rootstock combination was separated into 2 experimental groups. The first group was subjected to a desiccation test without cold storage, while the second group was wrapped with two layers of plastic sheet to minimize water loss and was stored in a 0 ± 2°C (32 ± 3.6°F) cold room at 85% ± 5% relative humidity (RH). At the end of cold storage period, plants were removed from the cold room, and subjected to a desiccation test.

For the desiccation test, individual trees were placed on a plastic sheet in the laboratory at 23 ± 2°C (73.4 ± 3.6°F), and 43% RH. Water loss was monitored by changes in fresh weight at 0, 6, 12, 24 and 48 hr. The top 7.6 cm (3 in) of the stem was excised and xylem water potential was measured by a PMS Instrument Company pressure chamber. A second piece of shoot tissue, approximately 15 cm (5.9 in) in length, from each plant was collected and fresh weight (FW) was measured immediately. The shoot tissue was oven dried in a 65°C (149°F) oven until a constant weight was reached to establish the dry weight (DW). Water content was expressed as gram water per gram dry weight, following the formula: gH_2O/g DW = (FW-DW)/DW.

Immediately following sampling for xylem water potential and water content measurements, each group of plants were transplanted into 25.4 cm (10 in) pots, containing a medium composed of sandy loam, pumice and peat moss (2:1:1, by vol), and placed in a greenhouse at 22 ± 5°C (72 ± 9°F) day and 15 ± 5°C (69 ± 9°F) night temperature under natural day length between April and August (12–14 hr). The light intensity at plant height measured at noon was approximately 100 $\mu E\ m^{-2}s^{-1}$ (475 fc). The number of shoots per plant, total fresh weight (FW) of new shoots per plant, percent scion survival (number of plants with at least 1 new shoot/total number of plants), and percent rootstock survival (number of plants with new root growth/total number of plants) were measured 30 days after treatment.

The rate of water loss from plant tissues was expressed as $\mathbf{k_1}$, the rate constant for the first order reaction. It was assumed that the release of tissue water into the air followed a first order reaction expressed as:

$$\frac{-dC}{dt} = k_1 C$$

where **C** is the initial water content of plant tissue; $\mathbf{k_1}$ is the rate constant of first order reaction; and **t** is time.

At a particular drying time, **t**, the amount of water loss is **x**. Therefore,

$$\frac{-dC}{dt} = \frac{-d(C - x)}{dt} = k_1(C - x)$$

The rate constant was obtained from the slope of the linear equation of $\log_{10}(C - x) = -(k_1/2.303)\ t + \log_{10} C$, when $\log_{10}(C - x)$ was plotted against **t**.

Analyses of variance (ANOVA) were conducted for all the traits measured using analysis of variance procedures in the Statistical Analysis System (SAS Institute, Inc., Cary, North Carolina, 1985). A factorial set of treatments: 10 scion/rootstock combinations, 5 desiccation treatments (0, 6, 12, 24 and 48 hr of drying), and 2 cold storage treatments (with or without cold storage) was replicated three times using a completely randomized design. Each experimental unit consisted of the 5 plants, and analyses were based on the mean of 5 plants. Tukey's multiple range test was used for mean separation of treatment effects at the 5% level. The % survival of rootstock and scions were transformed by arcsin for statistical analysis.

Results and Discussion

Shoot water potentials were measured in the trees at the beginning of the study. All trees showed water potential between −3.0 to −4.0 Mpa, indicating that they had experienced some degree of water stress during post harvest handling. However, the water stress experienced did not

Table 1. Effects of desiccation on the water contents and survival of bare-rooted apple trees without storage.

	Drying Time[a]					
	0 hr			48 hr		
	Water content	Survival (%)[y]		Water Content	Survival (%)	
Scion/root stock combination	(gH_2O/gDW)	Root	Scion	(gH_2O/gDW)	Root	Scion
Granny Smith/M.7	1.02 a[x]	100 a	100 a	0.73 a	80 ab	67 ab
MacIntosh/M.7	0.91 abc	100 a	100 a	0.55 bc	100 a	66 ab
Red Rome/M.7	0.93 abc	92 a	92 a	0.52 bc	22 c	11 cd
Super Jonagold/M.7	0.93 abc	89 a	89 a	0.60 ab	83 ab	56 ab
Red Jonagold/M.7	0.86 bc	100 a	100 a	0.48 bc	93 ab	0 d
Ryan Red Delicious/M.7	0.90 bc	100 a	100 a	0.43 c	77 ab	28 cd
Red Delicious/M.7	0.87 bc	100 a	100 a	0.53 bc	100 a	39 abcd
Red Delicious/MM.111	0.94 abc	100 s	100 a	0.54 bc	87 ab	80 a
Red Delicious/MM.106	1.00 ab	100 a	100 a	0.63 ab	80 ab	73 a
Red Delicious/Seedling	0.94 abc	100 a	100 a	0.56 bc	61 b	50 abc

[z]Trees were air dried at 23°C (73°F) and 43% RH.

[y]Root Survival = trees with new roots/total trees; Scion Survival = trees with new shoots/total trees.

[x]Means within columns followed by the same letters are not significant at p = 0.05 by Tukey's multiple range test.

affect their survival since all of the plant materials used in this study approached 100% survival after transplanting (Table 1).

The main effects of all three factors tested were highly significant except for the FW per shoot (Table 2). The two-way and three-way interactions were also significant for many of the traits studied. Because of the highly significant scion/rootstock combination X storage, and the treatment X storage interactions found in this study, valid comparisons among scion/rootstock combinations and desiccation treatments can be made only within each storage treatment.

The effects of desiccation on water content and the survival of bare-rooted apple trees are shown in Table 1. Prior to cold storage and desiccation treatments, the water content among the different scion/rootstock combinations had already differed significantly. The water content of shoot tissue ranged from 1.02 gH_2O/gDW in 'Granny Smith'/M.7 to 0.86 gH_2O/gDW in 'Red Jonagold'/M.7, however, there were no differences in either the shoot or root survival rate. After 48 hr of desiccation stress, however, the water content in the shoot tissue ranged from 0.43 g H_2O/gDW in 'Ryan Red Delicious'/M.7 to 0.73 gH_2O/gDW in 'Granny Smith'/M.7. The shoot survival rates were from 0% in 'Red Jonagold'/M.7 to 80% in 'Red Delicious'/MM.111. While root survival ranged from 22 to 100% indicating root survival was less affected by desiccation than that of scion survival.

After three months of cold storage, most of the plants showed significant reduction in water content, except 'Red Rome'/M.7 and 'Red Delicious'/MM.111 (Table 3). These two scion/rootstock combinations maintained about the same water contents as that prior to cold storage. In spite of the water loss during the cold storage, there was only a slight reduction in the survival of both scions or roots. During 48 hr of desiccation stress, the water content in the cold-stored trees was greatly reduced and shoot survival rates were 0% for most cultivars. Again, 'Red Delicious'/MM.111 showed the highest scion survival (41%), although its water content was lowered to 0.49 gH_2O/gDW. Root survival was affected much less by cold storage and desiccation treatments than scions.

Variation of durations of the drying treatment on cold stored bare-rooted apple trees of 'Red Delicious' scion on three different rootstocks indicated that drying about 12 to 24 hr reduced scion survival considerably (Figure 1). In spite of the difference in the initial water content, the water content after 48 hr of drying was almost the same, but survival rates varied among these three rootstock groups.

It appeared that both the scions and rootstocks affected the desiccation tolerance of bare-rooted apple trees. Among the scions grafted on to M.7 root stock, 'Granny Smith', 'MacIntosh', and 'Red Rome' had the highest desiccation tolerance. Among the combination of 'Red Delicious' on various rootstocks, 'Red Delicious' on MM.111 rootstock showed the greatest desiccation tolerance. The critical water content (i.e. the water content at which 50% of the plants survived) was about 0.5 gH_2O/g DW for all apple scion/rootstock combinations.

One possible explanation for the significant two-way and three-way interactions observed may be the fact that both cold storage and desiccation treatment resulted in the reduction in the water content of plant tissues. Without cold storage, most apple trees could tolerate up to 48 hr of drying or loss of water content to about 0.5 g H_2O/g F.W., i.e., 'Red Delicious' on MM.111 had 80% survival after 48 hr of drying. After storage, the plants still maintained a high survival percentage, however, 3 months of cold storage plus 48 hr of drying resulted in 0% survival for most cultivars. Again, 'Red Delicious'/MM.111 had the highest survival rate.

The first order rate constant was calculated to compare the rate of water loss from apple trees among different scion/rootstock combinations. All the plants used in this study showed similar patterns of water loss. Figure 2 shows a typical drying curve of the apple trees. When plotting the water contents vs drying time, in a semi logarithmic graph, the regression did not fit a straight line, indicating that the water loss was not a first order reaction. As shown in Figure 2, the data fit into two linear regressions with (k_1) of -3.1×10^{-2} and -1.5×10^{-2}, respectively. Trees of different scion/rootstock combinations have very similar drying curves

Table 2. Analysis of variance of the effect of cold storage and desiccation on water content, K_1, survival, shoot growth of 10 apple scions/rootstock combinations.

Source	df	Water content	K_1	Survival		Total shoot weight	Shoot number	FW/shoot
				Scion	Root			
Scion/root stock combination (SR)	9	**[z]	**	**	**	**	**	NS
Desiccation treatment (T)	4	**	**	**	**	**	**	**
Storage (ST)	1	**	**	**	**	**	**	**
SR × T	36	*	NS[y]	**	**	**	**	NS
SR × ST	9	**	**	**	**	**	**	NS
T × ST	4	**	NS	**	**	NS	*	**
SR × T × ST	36	NS	NS	NS	**	*	**	NS

[z]**, * = Significant at 1% and 5% level, resp.

[y]NS = Non-significant

Table 3. **Effects of desiccation on the water contents and transplanting survival of barerooted apple trees after 3 months of cold storage.**

Scion/root stock combination	Drying Time[z] 0 hr Shoot Water Content (gH_2O/gDW)	0 hr Survival (%)[y] Root	0 hr Survival (%)[y] Scion	48 hr Shoot Water Content (gH_2O/gDW)	48 hr Survival (%) Root	48 hr Survival (%) Scion
Granny Smith/M.7	0.68 bc[x]	92 ab	78 ab	0.48 abcd	28 de	0 b
MacIntosh/M.7	0.75 bc	100 a	100 a	0.56 ab	85 ab	8 b
Red Rome/M.7	0.91 a	100 a	100 a	0.58 a	44 cd	11 b
Super Jonagold/M.7	0.51 d	100 a	100 a	0.41 cd	0 e	0 b
Red Jonagold/M.7	0.72 bc	100 a	100 a	0.54 abc	100 a	0 b
Ryan Red Delicious/M.7	0.65 bc	100 a	100 a	0.49 abcd	80 ab	0 b
Red Delicious/M.7	0.52 cd	81 b	64 b	0.39 d	0 e	0 b
Red Delicious/MM.111	0.94 a	100 a	100 a	0.49 abc	67 bc	41 a
Red Delicious/MM.106	0.69 bc	100 a	100 a	0.42 bcd	60 bcd	0 b
Red Delicious/Seedling	0.63 bcd	100 a	69 b	0.46 abcd	44 cd	0 b

[z]Trees were air dried at 23°C (73°F) and 43% RH.

[y]Root Survival = trees with new roots/total trees; Scion Survival = trees with new shoots/total trees.

[x]Means within columns followed by the same letters are not significant at p = 0.05 by Tukey's multiple range test.

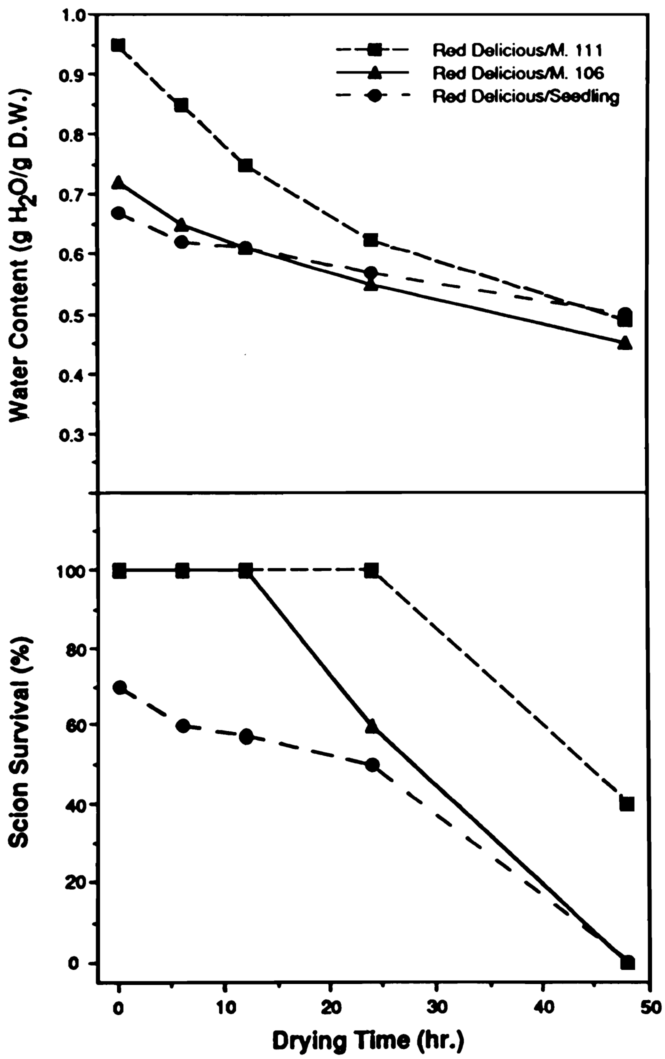

Fig. 1. Effects of the duration of drying on the water contents and transplant survival of 'Red Delicious' scions on three different rootstocks. Trees were stored at 0°C (32°F) for 3 months prior to drying treatment.

as that shown in Figure 2, except the k_1 values were different.

Analysis of the kinetics of water loss from bare-rooted trees indicated it was not a first order reaction. If it is a true first order reaction, the k_1 value calculated from a different region of the drying curve should be identical. For each scion/rootstock combination, the k_1 values from 0–6 hr are similar and much higher than the k_1's calculated for 12–48 hr of drying. However, the data fit a double first order reaction. For example, in 'Red Delicious'/MM.111 trees (Fig. 2), a fraction of water was lost at a greater rate ($k_1 = -3.1 \times 10^{-2}$) in the first 6 hr, followed by a fraction of water released from tissue at a slower rate ($k_1 = -1.5 \times 10^{-2}$) between 12 and 48 hr of drying. The simplest interpretation of the data would be that water resided in two different compartments, such that during the drying period, water in one compartment released faster into the dry air, while the water in the second compartment released at a slower rate. The data does not provide an explanation of the nature of compartmentalization. While trees of a compound genetic system were used in the desiccation test, it

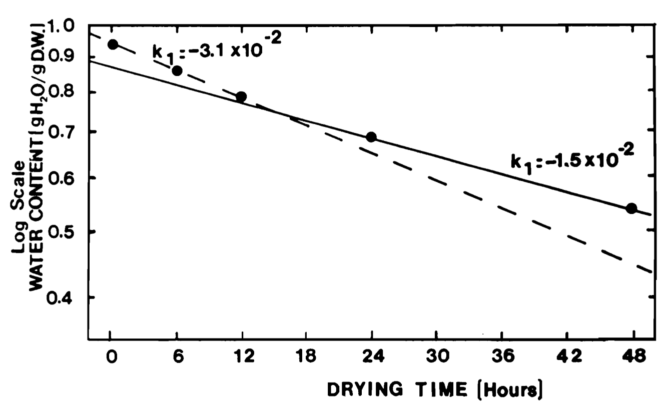

Fig. 2. Example of the kinetics of water loss as a function of the duration of drying in bare-rooted apple trees, stored at 0°C (32°F) for 3 months.

is possible that root tissue represents the first water compartment and shoot tissues represents the second compartment. Similar analyses have been conducted on the root and shoot tissues of *Betula pubescens* and *Fraxinus angustifolia* (4). In both species, the moisture content in log scale was plotted separately against time of drying for root tissue and shoot tissue. They observed a straight line for shoot and one for root with different slopes, indicating that water released into dry air follows a first order reaction when analyzed separately for root and shoot tissues. Since we used whole trees for measuring drying response, it is possible the double first order reaction may be representing one reaction for root tissue and one for shoot tissue. It is also possible that the water in different cell types (for example, bark vs. wood tissues) may be the reason for the compartmentalization. Experiments are underway to clarify this point.

Results show that 'Red Delicious' scion with a MM.111 rootstock is more desiccation tolerant than other rootstocks tested. Its higher degree of desiccation tolerance seemed to be a result of its ability to tolerate more water loss from tissue. This conclusion is based on the observation that both the rate of water loss from the tissue and the critical water contents of 'Red Delicious'/MM.111 could not explain its superior desiccation tolerance.

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Improvement of Seedling Emergence of *Lupinus texensis* Hook. Following Seed Scarification Treatments[1]

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Abstract

Seeds from four commercial seedlots of *Lupinus texensis* Hook. (Texas bluebonnet) were placed in concentrated sulfuric acid for 0 to 120 minutes and then sown. Emergence was promoted by acid scarification in three of the four seedlots. For the lots that responded to acid scarification, the optimal scarification time was 30–60 minutes which resulted in 85–95% emergence one month after planting. In addition to increasing the total number of seedlings that emerged, acid scarification hastened emergence. The same aliquot of sulfuric acid was used for five 60-minute scarification periods before its efficacy was reduced. Acid scarification did not reduce seed coat thickness or strength but created several small pores in the seed coat which likely facilitated imbibition. Cutting, filing, or piercing the seed coat promoted emergence to a similar extent. Placement of seeds in 85°C (185°F) water and then cooling for 24 hrs promoted emergence relative to the non-treated controls, but was not as effective as other scarification techniques. Freezing and thawing of seeds had no effect on emergence. Results indicate that acid scarification functions by removing a mechanical rather than a chemical barrier to germination of *L. texensis*.

Index words: germination, native plants, seed propagation, sexual propagation, sulfuric acid, Texas bluebonnet

Significance to the Nursery Industry

Lupinus texensis is a potentially useful low maintenance annual but, as with other newly-domesticated species, propagation may be an obstacle to further development. Our findings indicate that considerable seedlot variability exists with regard to the need for sulfuric acid scarification. Growers should test the response of small seedlot samples to acid scarification before deciding on the length of the acid scarification period. If this is not possible, then a 45-minute acid treatment should promote emergence in most seedlots of *L. texensis* without causing significant damage to the sensitive lots. A given quantity of sulfuric acid can be used for at least five scarification treatments before its efficacy

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