Vegetative Propagation of *Ratibida columnifera* (Nutt.) Wooton & Standl.

Kaitlin A. Hopkins  
School of Agricultural Sciences, Sam Houston State University, 1019 Bowers Blvd, Huntsville, TX 77340

Michael A. Arnold and Charles R. Hall  
Department of Horticultural Sciences, Texas A&M University, 2133 TAMU, College Station, TX 77843-2133

Brent Pemberton  
Texas A&M Agricultural Research and Extension Center, P.O. Box 200, Overton, TX 75684

Marco A. Palma  
Department of Agricultural Economics, Texas A&M University, 2124 TAMU, College Station, TX 77843-2124

Additional index words. Asteraceae, bottom heat, IBA, prairie coneflower, rooted stem cuttings

**Abstract.** Variation in floral characteristics and growth habits within the native range of the North American wildflower *Ratibida columnifera* (Nutt.) Wooton & Standl. suggest potential for breeding and selection efforts to develop improved cultivars for commercial and residential landscapes. Toward that end, experiments in vegetative propagation were performed to enable perpetuation of unique germplasm. Stem development stage, applications of auxin, genotypic variation, and the effects of bottom heat applications were assessed to determine impacts on rooting percentages and adventitious root system quality measures. Younger apical stem sections rooted more readily and produced better quality root systems than more lignified basal stem cuttings. Optimal rooting percentages and rooted cutting quality ranged from 0.10% to 0.30% IBA (indole-3-butyric acid) quick dips, with 0.30% being optimal for most genotypes. Application of 26 °C bottom heat improved rooting ability in both cool and warm seasons compared with ambient and bottom heat of 32 °C. Bottom heat of 32 °C improved most rooting measures over ambient during the cool season, but not during the warm season. The degree of improvement in adventitious rooting associated with various developmental stage, auxin quick dips, and bottom heating varied among accessions of *R. columnifera*, suggesting that adventitious rooting characteristics should be evaluated as a selection criterion for cultivar development within this species.

Vegetative propagation is vital to preservation of unique natural variants and allows capture of both additive and nonadditive variance in breeding programs (Wassner and Ravetta, 2000). This allows for efficient clonal reproduction of desired germplasm. Propagation techniques vary depending on species; therefore, it would be effective and efficient to know a propagation protocol for the species in question. *Ratibida columnifera* (Nutt.) Wooton & Standl. [syn. *Lepachys columnifera* (Nutt.) J.F. Macbr., *Ratibida columnaris* (Pursh) D. Don, *Rudbeckia columnaris* Pursh, *Rudbeckia columnifera* Nutt.] is most commonly known as prairie coneflower or Mexican hat, but is also referred to by a number of regional common names including columnar prairie coneflower, longhead-coneflower, redspike Mexican hat, thimble flower, or upright prairie coneflower (Tropicos.org, 2018; U.S. Department of Agriculture, Natural Resource Conservation Service, 2006). This species is readily available via seed and seedlings but does not currently have a vegetative propagation protocol using stem cuttings. In tissue culture, *R. columnifera* will respond to cytokinin application by growing shoots, and auxin by growing callus and roots (Holden et al., 1976). This is promising and suggests that auxin may also initiate callus and rooting in stem cuttings for *R. columnifera*. In a study of *Grindelia*, another member of the Asteraceae Bercht. & J. Presl family, cuttings were exposed to IBA in various concentrations, which resulted in differential effectiveness of adventitious rooting (Wassner and Ravetta, 2000). It is important to identify the optimum concentration of IBA to use, because too low or too high levels can adversely impact rooting quality. In general, when using stem cuttings, young basal shoots are typically more suitable than mature stems for most wildflower species (Trinklein, 2014). In the study of *Grindelia*, cutting position was the most important variable influencing rooting success (Wassner and Ravetta, 2000). In that study, they used apical (upper 6–8 nodes) and basal (lower 6–8 nodes) to evaluate the effect of cutting position on rooting. Other studies have also shown that more heavily lignified cuttings are more difficult to root than younger stems (Hartmann et al., 2010). For this reason, the developmental stage of the cutting was examined for *R. columnifera*. The study on *Grindelia* also showed that rooting success differed among different geographical accessions (Wassner and Ravetta, 2000), which leads us to believe that might be the case for *R. columnifera* accessions as well. Environmental conditions such as differences in temperature also can have a significant effect on rooting (Castaneda-Saucedo et al., 2020), and therefore needs to be explored further in *R. columnifera*. A seasonal rooting capacity is reported in other perennial species between cuttings rooted in summer and autumn (Sharma and Aier, 1989). This suggests a need for replication of studies in both cooler and warmer seasons.

This study is designed to answer several cultural components for effective adventitious rooting of stem cuttings of *R. columnifera*, including the effects of developmental stage of cuttings on rooting percentage and root quality, optimum hormone concentrations for maximum rooting responses, effects of bottom heat during rooting, and variation in adventitious rooting from stem cuttings among genotypes.

**Materials and Methods**

There were two vegetative propagation experiments (effects of hormone concentrations and developmental stages on rooting; effects of bottom heat application and germplasm on rooting), with the bottom heat experiment replicated once in warm temperature conditions and once in cool temperature conditions. The experiment involving factorial combinations of hormone concentrations and developmental stage of cuttings examined rooting effects of developmental stages (young vs. mature) and four concentrations of IBA (0, 0.1%, 0.3%, or 0.8% IBA; OHP INC., Mainland, PA) on 30 cuttings of each treatment combination for a total of 240 cuttings.

**Rooting hormone and developmental stage**

Rooting hormone and development stage experiments involved one germplasm, accession TX RC 8 (College Station, TX, lat. 30.61167 N 30°36′42″0906″, long. −96.35342 W 96°21′12″31.423″). This experiment took place in June 2019. TX RC 8 stock plants were located in a full-sun section of the nursery. Stock plants were planted in nursery crop substrate (Metro Mix 902; SunGro, Agawam, MA) and top dressed with 15N–3.93P3·9.96K slow-release fertilizer (Osmocote plus, 15–9–12. Patterned release fertilizer, 8–9 month; Everras ICL, Dublin, OH). Photosynthetically active radiation (PAR) in the full-sun location was an average of 1638 μmol m⁻² s⁻¹ photosynthetic photon flux density (PPFD) during midday,
whereas in the overwintering house averaged 833.3 μmol·m−2·s−1 PPFD during midday (Fieldscout Quantum Foot-Candle Meter; Spectrum Technologies, Inc., Aurora, IL). Plants were grown in 14.5-L pots (Trade size #5, blow-molded-classic line; Nursery Supplies Inc., Chambersburg, PA). During warmer months of the year (April–October), the stock plants were in full-sun nursery conditions, watered on an as-needed basis, and fertilized to the leaching point weekly with 20–20–20 water-soluble fertilizer (Peters Professional 20–20–20 General Purpose; Everris ICL). Greenhouse temperatures where the misting benches were located were 32°C maximum and 21°C minimum. Light conditions in this greenhouse were an average of 319.9 μmol·m−2·s−1 PPFD during midday (Fieldscout Quantum Foot-Candle Meter; Spectrum Technologies, Inc.). Each treatment combination was composed of 30 stem cuttings each for a total of 240 cuttings. Propagules for this study consisted of a stem cutting with three nodes. Shoots of *R. columnifera* have inflorescences on the apical portion of mature stems. Cuttings were taken from developmentally uniform shoots with inflorescences, which were removed before sticking. The young developmental stage was composed of apical three-node-long stem-tip cuttings. The mature developmental stage cuttings were three-node-long cuttings taken from the more basipetal portion of the stem that had become fibrous. Aqueous solutions of IBA at four concentrations (0.0%, 0.3%, or 0.8% IBA; OHP, INC., Mainland, PA) were applied to the basal 4 cm of cuttings via a 5-s soak before planting in moistened perlite (Sunshine Perlite, premium grade; Sungro) in 10 × 36 × 51-cm (4 × 14 × 20-in) black plastic nursery flats (Dyna-flat; Kadon Corp., Dayton, OH). They were then placed under intermittent mist (10 s every 15 min from dawn to dusk) for the duration of 30 d with natural photoperiods. Greenhouse temperatures were 32°C maximum and 21°C minimum. At 30 d after planting, cuttings were harvested by gently removing them from the perlite and rinsing in a beaker of water to clean off the media. Qualitative measurements such as callus/root formation and a visual rating were gathered. The visual rating was on a scale of 1 (poor) to 5 (excellent), with a rating of 3 being the minimally acceptable quality rooting for commercial production (Fig. 1). Quality was judged by how vigorous rooting was, for example, if there were many dense fibrous roots as opposed to a few long sparse roots. A rating of 1 (poor) was given to cuttings that failed to generate callus or roots. A rating of 2 was given to cuttings that generated some callus and a few non-branching roots. A rating of 3 was given to cuttings that produced many roots with some branching. A rating of 4 was given to cuttings with even more roots with branching. A rating of 5 (excellent) was given to cuttings that produced numerous branching roots.

Quantitative measurements included the measurement of the five longest roots (cm), primary basal root number, root dry mass (g), and proportion of cuttings generating one or more roots (rooted cuttings) and those exhibiting rooting or callus (callused cuttings).

A randomized complete block design was used for this experiment. Factorial combinations of two developmental stages and four IBA combinations were arranged in three blocks, each containing 10 replicates of each treatment combination. Analysis of variance, generalized linear model (GLM), and Tukey’s honestly significant difference (HSD) were used for the interactions among rooting hormone concentrations and developmental stages, with $P \leq 0.05$ for significance using JMP Pro 15 (SAS Institute Inc., Cary, NC) for continuous and categorical variables.

**Seasonal effects of bottom heat and genotype**

This experiment examined rooting effects of bottom heat application [no additional heat (ambient with greenhouse temperature of ≥23°C), 26°C, or 32°C] and three genotypes (accession TX RC 8, College Station, TX, lat. 30.61167 N 30 3642.02903°, long. –96.35342 W 96 21.123142°, accessions TX RC 29 and TX RC 30, Somerville, TX, lat. 30.522288 N, long. –96.429397 W) at 30 cuttings (three replications of 10 cuttings) of each combination for a total of 270 cuttings. This experiment was replicated once during the warm season (Sept. 2019), and once during the cool season (Jan. 2020). Results from earlier experiments with IBA and developmental stages were used to determine the use of 0.3% IBA and young developmental stage for all cuttings in the bottom heat and genotype experiments. Stock plants during September were located in a full-sun section of the nursery, whereas stock plants in January were located in filtered light in the overwintering house (polyethylene sheeting, not climate controlled). PAR in the full-sun location was an average of 1638 μmol·m−2·s−1 PPFD during midday, whereas the overwintering house averaged 833.3 μmol·m−2·s−1 PPFD during midday (Fieldscout Quantum Foot-Candle Meter; Spectrum Technologies, Inc.). Stock plants were planted in nursery crop substrate (Metro Mix 902; Sungro) and top dressed with 15N–3.933P–9.96K slow-release fertilizer (Osmocote plus, 15–9–12, Patterned release fertilizer, 8–9 month; Everris ICL). Plants were grown in 14.5-L pots (Trade size #5, blow-molded-classic line; Nursery Supplies Inc.). Stock plants were watered on an as-needed basis, and fertilized to the leaching point weekly with 20–20–20 water-soluble fertilizer (Peters Professional 20–20–20 General Purpose; Everris ICL). Aqueous solutions of 0.3% IBA were applied to cuttings via a 5-s soak before planting in moistened perlite (Sunshine Perlite, premium grade; Sungro). Germination mats (Model PM-9A, Pro-Grow Supply Corp., Brookfield, WI; Redi-Heat Model RHD2105, Phyto- tronics Inc., Earth City, MO) with temperature soil probes were used to consistently heat the media to the appropriate temperature for the duration of the experiment (Redi-Heat thermostat, Model RHT4, Phyto- tronics, Inc.). During this experiment, greenhouse temperatures were 32°C maximum and 21°C minimum, and light conditions were an average of 319.9 μmol·m−2·s−1 PPFD during midday (Fieldscout Quantum Foot-Candle Meter, Spectrum Technologies, Inc.). Cuttings were placed...
under intermittent mist (10 s every 15 min from dawn to dusk). At 30 d after planting, cuttings were harvested by gently removing them from the perlite and rinsing in a beaker of water to clean off the media. Qualitative measurements such as callus/root formation and a visual rating (as previously described) were gathered. Quantitative measurements included the measurement of the five longest roots (cm), root number, root dry mass (g), and proportion of cuttings generating one or more roots. A randomized complete block design was used for this experiment. Factorial combinations of three bottom heat temperatures and three genotypes were arranged in three blocks, each containing 10 replicates of each treatment combination. The entire experiment was then replicated in time (Sept. 2019, Jan. 2020). When appropriate, analysis of variance, GLM, and Tukey’s HSD were used for the interactions among bottom heating and genotypes with $P \leq 0.05$ for significance using JMP Pro 15 for continuous and categorical variables (SAS Institute Inc.).

Results and Discussion

Rooting hormone and developmental stage

Auxin concentration and developmental age of cuttings significantly affected many aspects of root regeneration (Table 1). Models for all four root regeneration measures were significant. Interactions among IBA concentrations and stem developmental stages were significant for root length, number, and root dry mass (Table 1). Young cuttings with 0.10% IBA outperformed all other young tissue cuttings with a root length average of 6.5 cm. Mature cuttings with 0.00% IBA and 0.30% IBA were not significantly different from the young cuttings with 0.10% IBA. Young cuttings had longer roots with 0.10%, and had less rooting success when no IBA was applied. Mature cutting root lengths were not significantly different from one another. Root number was significantly affected by both the main effects of hormone concentration and age ($P < 0.0001$) and had a significant interaction (Table 1). Young cuttings produced the greatest root number at 0.30% IBA, followed by 0.80% IBA, then 0.10% IBA, with the least number of roots resulting from 0.00% IBA. Mature cuttings produced the greatest root number at 0.80% IBA, followed by 0.30% IBA, then 0.10% IBA, with the least number of roots being produced with 0.00% IBA. Hormone concentration and developmental age had significant main effects on rooting quality, but their interaction was not significant (Table 2). In terms of rooting quality ratings, young cuttings and 0.10% IBA and 0.30% IBA improved rooting quality when compared with the control (Table 2). Both young and mature cuttings produced the best quality roots in the midrange hormone concentrations (0.10% IBA and 0.30% IBA), and the worst quality roots in the hormone concentration extremes (0.00% IBA and 0.80% IBA). There was a significant interaction for root dry mass among IBA concentrations and developmental stages (Table 1). Overall, the mature cuttings had a larger mass than the young cuttings. Hormone concentration and developmental stage of cutting did not have a significant effect on the proportion of cauliflorous cuttings ($P = 0.7788$, data not presented).

This experiment involved many significant interaction effects between cutting developmental stage and hormone concentration. Across the board, a low to midrange hormone concentration of 0.10% or 0.30% improved rooting quality on both developmental stages in comparison with the control. This reinforces the suggestion that application of auxin will initiate root formation (Holden et al., 1976), specifically in members of the Asteraceae (Wassner and Ravetta, 2000). Higher concentrations had more numerous roots that were slightly shorter in length. Absence of hormone generated fewer roots that were slightly longer in length. A desirable ratio of root number to root length could be achieved by application of a midrange hormone concentration. This is reflected in the root quality scale, where 0.10% and 0.30% on young tissue yielded the highest quality roots. This is consistent with the claim that young tissue is more suitable for vegetative propagation than mature tissue (Trinklein, 2014). This may be because of the heavier lignification that is often found in mature tissues (Hartmann et al., 2010). If necessary, cuttings can be taken when plants are more mature, but this often requires the use of rooting hormones (Perry, 1998). This statement held true for certain rooting qualities like root number for Rathibida columnifera. For this reason, it is recommended that for the optimum overall root quality in R. columnifera, one should apply 0.30% IBA to young developmental stage cuttings.

Seasonal effects of bottom heat and genotype

Warm season. Germlub and bottom heat applications to cuttings during warm ambient temperatures significantly affected many aspects of adventitious rooting (Tables 3 and 4). Interactions among bottom heats and germplasms were present for root number and root quality ratings, but were not significant for root length, root dry mass, or proportion of cuttings rooting (Tables 3 and 4). Main effects of germlub were significant for all root regeneration measures and the main effects of bottom heats were significant for all but root dry mass (Tables 3 and 4). The ambient and 32°C treatments were not significantly different from each other except with regard to dry mass and proportion rooting (Table 4). TX RC 8 and TX RC 30 had significantly longer roots than TX RC 29 regardless of which bottom heat treatment they received (Table 4). For TX RC 8, 26°C bottom heat application yielded the greatest root number, with ambient temperature and 32°C inducing no significant difference from each other. TX RC 29 had no significant differences in number of roots generated among

\begin{table}[ht]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Developmental stage & Hormone treatment & Root length (cm) & Root number & Dry mass (g) \\
\hline
Young & 0.00% IBA & 3.48 b & 9.13 d & 0.20 c* \\
 & 0.10% IBA & 6.54 a & 26.9 c & 0.27 abc \\
 & 0.30% IBA & 4.58 b & 39.47 a & 0.22 bc \\
 & 0.80% IBA & 4.28 b & 30.8 bc & 0.20 c \\
Mature & 0.00% IBA & 5.02 ab & 14.6 d & 0.29 ab \\
 & 0.10% IBA & 4.81 b & 24.9 c & 0.26 bc \\
 & 0.30% IBA & 5.18 ab & 34.9 ab & 0.30 ab \\
 & 0.80% IBA & 3.71 b & 38.4 a & 0.34 a \\
\hline
Treatment effects & Whole model & <0.0001* & <0.0001* & <0.0001* \\
 & Hormone concn. & 0.0001* & <0.0001* & 0.618 \\
 & Dev. age & 0.8875 & 0.1838 & <0.0001* \\
 & Conc. × age & 0.0003* & 0.0010* & 0.0001* \\
\hline
\end{tabular}
\caption{Effect of indole-3-butyric acid (IBA) concentrations and developmental age of cuttings on rooting success of germplasm TX RC 8.}
\end{table}

\begin{table}[ht]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Main effect & Treatment & Rooting quality rating \\
\hline
IBA concentration & 0.00% IBA & 3.57 b* \\
 & 0.10% IBA & 4.10 a \\
 & 0.30% IBA & 4.15 a \\
 & 0.80% IBA & 3.33 b \\
Developmental age & Young & 3.95 a \\
 & Mature & 3.63 b \\
Treatment effects & Whole model & <0.0001* \\
 & Hormone concn. & <0.0001* \\
 & Dev. age & 0.0253* \\
 & Conc. × age & 0.0749 \\
\hline
\end{tabular}
\caption{Effect of indole-3-butyric acid (IBA) concentration and developmental age of cutting on rooting quality rating of germplasm TX RC 8.}
\end{table}

*Tukey’s honestly significant difference mean comparison levels not followed by same letter within a column are significantly different ($P \leq 0.05$). Effects that are statistically significant are labeled *.
The three bottom heat applications, TX RC 30 had the most roots with 26°C, with ambient and 32°C treatments eliciting no significant difference from each other (Table 3). TX RC 8 had the best root quality with 26°C bottom heat application, and with ambient temperatures and 32°C treatments having no significant difference. TX RC 29 had no significant differences among the three temperatures on root quality. TX RC 30 had the best quality roots at 26°C, with ambient and 32°C treatments producing no significant differences (Table 3). TX RC 8 had significantly more root mass than TX RC 29 or TX RC 30. Bottom heat application of 26°C induced a significantly greater proportion of cuttings to root than the other two heat applications (Table 4). TX RC 8 had the highest proportion of rooting of the three germplasms, followed by TX RC 30 and then TX RC 29 (Table 4).

Recommendations for bottom heat use when vegetatively propagating *R. columbaria* during the warm season are as follows. Regarding bottom heat treatments, 26°C bottom heat significantly improved the following aspects: root length, root number, root quality, and proportion rooting in most of the germplasms. Application of 26°C bottom heat to the rooting substrate proved to be beneficial to rooting success, consistent with the claim that environmental conditions such as differences in temperature can also have a significant effect on rooting of another member of Asteraceae, *Stevia rebaudiana* (Bertoni) Bertoni (Castaneda-Saucedo et al., 2020). In almost every treatment combination, germplasm TX RC 8 had improved rooting characteristics compared with the other two germplasms. One interesting result was that TX RC 29 root quality characteristics were unaffected by bottom heat application in all but a proportion of cuttings rooted. This shows that different germplasm react differently to bottom heat treatments. This coincides with the suggestion that rooting success differed among different geographical accessions of *Grindelia* (Wassner and Ravetta, 2000).

Cool season. Germplasms and bottom heat applications to cuttings during cool ambient temperatures significantly affected several aspects of adventitious root formation but did not result in any significant interactions among germplasms and bottom heats (Table 5). Main effects of germplasms were significant for all rooting measures during the cool season and main effects of bottom heat were significant for root length and rooting proportions (Table 5). Across germplasms, 26 and 32°C bottom heat applications stimulated growth of longer roots during the cool season, when compared with ambient temperatures (Table 5). TX RC 30 had the longest roots, followed by TX RC 8, with TX RC 30 having the shortest roots. TX RC 30 produced the greatest root number, followed by TX RC 8 and TX RC 29. TX RC 30 produced the highest quality roots, followed by TX RC 8 and then TX RC 29. Root dry mass had no significant differences among the treatment combinations during the cool season (P ≥ 0.0776, data not presented). Proportion of rooting was significantly affected by bottom heat application and germplasm (P ≤ 0.0001), with no interaction effects (P ≤ 0.0667). The 26 and 26°C bottom heat applications had a greater proportion of total cuttings generate roots when compared with the ambient temperature treatment for all genotypes during the cool season. TX RC 30 had the greatest proportion of cuttings to root, followed by TX RC 8 and then TX RC 29 (Table 5).

The cool season replication of the bottom heat application experiment had differing results from the warm season. In aspects in which there were significant differences, 26 and 32°C were favorable over ambient temperatures. There was no significant difference between the 26 and 32°C temperature treatments during the cool season, whereas 32°C did not improve rooting in the warm season while 26°C did improve rooting (Table 2). The germplasm performance was very consistent from treatment to treatment, with TX RC 30 always outperforming TX RC 8, and TX RC 8 always outperforming TX RC 29. This demonstrates that rooting success differs among geographical accessions for *R. columbaria* (and appears to be consistent within, but not necessarily between seasons), similar to results reported on *Grindelia* (Wassner and Ravetta, 2000). Reports on *S. rebaudiana* state that temperatures, both of the environment and substrate, have significant effects on rooting (Castaneda-Saucedo et al., 2020), which held true for *R. columbaria*. Differing environmental temperatures between the cool and warm season did affect the seasonal rooting capacity for *R. columbaria*, as has been reported with woody perennial species between summer and autumn rooted cuttings (Sharma and Aier, 1989). It is recommended that when attempting to root *R. columbaria* cuttings in the cool season, one should apply between 26 and 32°C bottom heat to achieve optimum rooting. Root zone heating can also allow for cold-tolerant crops to be propagated at lower air temperatures, as described in a report on Calibrachoa, *Campanula*, *Nemesia*, *Nepeta*, *Osteosperum*, *Petunia*, and *Phlox* (Kohler and Lopez, 2021). It is suggested that bottom heat should be used when the temperature of the growing mix drops below 21°C, with most cuttings rooting best in media temperatures between 21 and 26°C (Perry, 1998). The application of 26°C bottom heat improved *R. columbaria* rooting in both the cool and warm seasons.

Unless specific data are available for a given genotype, results of our experiments suggest using a 26°C bottom heat, young recently matured shoot tips, and 0.10% IBA to 0.30% IBA quick dips to maximize adventitious root development. Results of these

---

**Table 3.** Significant interaction effects of bottom heat application on root number and rooting quality of germplasm TX RC 8, TX RC 29, and TX RC 30 during warm seasons.

<table>
<thead>
<tr>
<th>Germplasm</th>
<th>Bottom heat temp (°C)</th>
<th>Root number</th>
<th>Rooting quality rating scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>TX RC 8</td>
<td>Ambient (23°C)</td>
<td>18.8 b</td>
<td>1.60 bcd</td>
</tr>
<tr>
<td></td>
<td>Bottom heat (26°C)</td>
<td>23.0 b</td>
<td>1.30 b</td>
</tr>
<tr>
<td></td>
<td>Bottom heat (32°C)</td>
<td>23.0 b</td>
<td>1.82 bc</td>
</tr>
<tr>
<td>TX RC 29</td>
<td>Ambient (23°C)</td>
<td>3.97 c</td>
<td>1.07 d</td>
</tr>
<tr>
<td></td>
<td>Bottom heat (26°C)</td>
<td>6.20 c</td>
<td>1.07 d</td>
</tr>
<tr>
<td></td>
<td>Bottom heat (32°C)</td>
<td>4.23 c</td>
<td>1.13 d</td>
</tr>
<tr>
<td>TX RC 30</td>
<td>Ambient (23°C)</td>
<td>8.07 c</td>
<td>1.30 cd</td>
</tr>
<tr>
<td></td>
<td>Bottom heat (26°C)</td>
<td>18.3 b</td>
<td>1.97 b</td>
</tr>
<tr>
<td></td>
<td>Bottom heat (32°C)</td>
<td>5.47 c</td>
<td>1.13 d</td>
</tr>
<tr>
<td>Treatment effects</td>
<td>Whole model</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Bottom heat</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Germplasm</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Bottom heat × germplasm</td>
<td>0.0021*</td>
<td>&lt;0.0001*</td>
</tr>
</tbody>
</table>

*Tukey’s honestly significant difference mean comparison levels not followed by same letter within a column are significantly different (P ≤ 0.05). Effects that are statistically significant are labeled *.  

---

**Table 4.** Effect of bottom heat application on rooting success of germplasm TX RC 8, TX RC 29, and TX RC 30 during warm season.

<table>
<thead>
<tr>
<th>Main effect</th>
<th>Treatment</th>
<th>Root length (cm)</th>
<th>Dry mass (g)</th>
<th>Proportion rooting (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom heat</td>
<td>Ambient (23°C)</td>
<td>1.31 b</td>
<td>0.12 a</td>
<td>54 b</td>
</tr>
<tr>
<td></td>
<td>Bottom heat (26°C)</td>
<td>2.21 a</td>
<td>0.13 a</td>
<td>80 a</td>
</tr>
<tr>
<td></td>
<td>Bottom heat (32°C)</td>
<td>1.34 b</td>
<td>0.12 a</td>
<td>64 b</td>
</tr>
<tr>
<td>Germplasm</td>
<td>TX RC 8</td>
<td>2.12 a</td>
<td>0.14 a</td>
<td>84 a</td>
</tr>
<tr>
<td></td>
<td>TX RC 29</td>
<td>0.93 b</td>
<td>0.10 b</td>
<td>48 c</td>
</tr>
<tr>
<td></td>
<td>TX RC 30</td>
<td>0.179 a</td>
<td>0.11 b</td>
<td>67 b</td>
</tr>
<tr>
<td>Treatment effects</td>
<td>Whole model</td>
<td>&lt;0.0001*</td>
<td>0.0003*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Bottom heat</td>
<td>&lt;0.0001*</td>
<td>0.107</td>
<td>0.0006*</td>
</tr>
<tr>
<td></td>
<td>Germplasm</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Bottom heat × germplasm</td>
<td>0.1113</td>
<td>0.3624</td>
<td>0.9312</td>
</tr>
</tbody>
</table>

*Tukey’s honestly significant difference mean comparison levels not followed by same letter within a column are significantly different (P ≤ 0.05). Effects that are statistically significant are labeled *.  

---
studies also suggest that to maximize commercial production, candidate genotypes for introduction should be screened for general rooting potential before release.

**Literature Cited**


---

**Table 5. Effects of bottom heat applications on rooting success of *Ratibida columnifera* germplasm TX RC 8, TX RC 29, and TX RC 30 during cool seasons.**

<table>
<thead>
<tr>
<th>Main effect</th>
<th>Treatment</th>
<th>Root length (cm)</th>
<th>Root number</th>
<th>Rooting quality rating scale</th>
<th>Proportion rooting (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ambient (23°C)</td>
<td>11.25 b</td>
<td>14.60 a</td>
<td>1.32 a</td>
<td>59 b*</td>
</tr>
<tr>
<td></td>
<td>Bottom heat (26°C)</td>
<td>22.30 a</td>
<td>20.79 a</td>
<td>1.58 a</td>
<td>78 a</td>
</tr>
<tr>
<td></td>
<td>Bottom heat (32°C)</td>
<td>21.00 a</td>
<td>17.49 a</td>
<td>1.54 a</td>
<td>79 a</td>
</tr>
<tr>
<td>Germplasm</td>
<td>TX RC 8</td>
<td>16.77 b</td>
<td>18.31 b</td>
<td>1.43 b</td>
<td>70 b</td>
</tr>
<tr>
<td></td>
<td>TX RC 29</td>
<td>10.56 c</td>
<td>6.03 c</td>
<td>1.12 c</td>
<td>56 b</td>
</tr>
<tr>
<td></td>
<td>TX RC 30</td>
<td>27.24 a</td>
<td>28.53 a</td>
<td>1.89 a</td>
<td>90 a</td>
</tr>
<tr>
<td>Treatment effects</td>
<td>Whole model</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Bottom heat</td>
<td>&lt;0.0001*</td>
<td>0.1034</td>
<td>0.0677</td>
<td>0.0017*</td>
</tr>
<tr>
<td></td>
<td>Germplasm</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td></td>
<td>Bottom heat × germplasm</td>
<td>0.1856</td>
<td>0.0974</td>
<td>0.4045</td>
<td>0.0667</td>
</tr>
</tbody>
</table>

*Tukey’s honestly significant difference mean comparison levels not followed by same letter within a column are significantly different (P ≤ 0.05). Effects that are statistically significant are labeled *. 