Journal of the American Pomological Society 75(1): 9-16 2021

Alkaline Soil Tolerance of Rootstocks included in the NC-140 'Redhaven' Peach Trial

B.L. Black[1], I.S. Minas[2], G.L. Reighard[3], T. Beddes[4]

Additional index words. *Prunus persica*, interspecific hybrids, plum, almond, soil pH.

Abstract

Prunus rootstocks budded to 'Redhaven' peach were planted at 3 locations in the Intermountain West region of North America as part of the 2009 NC-140 peach trial. The three locations were similar in climate and elevation but differed in soil texture and pH. Tolerance to soil conditions was evaluated by comparing tree growth across the 3 locations over 9 years and by measuring leaf chlorophyll content annually at the most alkaline site. Tree growth had a strong location by rootstock interaction. Comparing relative tree growth between the two Utah sites indicated that tolerance to the more alkaline soil was related to genetic background, where *P. persica* rootstocks were least tolerant, selections from other species were most tolerant, and hybrids containing *P. persica* background were intermediate. Leaf chlorophyll measurements to compare iron chlorosis showed similar correlations with genetic background. Tree growth at the Colorado location did not show the same correlation and may be due to differences in soil texture.

Peach [*P. persica* (L.) Batsch] is an important fruit crop for the high elevation Intermountain West region of the U.S. and the most important fruit crop for Colorado, with over 1,050 ha, more planted area than apple or grape (NASS, 2019). In Utah, the ~480 ha in peach production ranks second only to tart cherry in planted area of fruit crops (NASS, 2019). Much of the peach production in these two states occurs at elevations above 1,300 m. Fruit that ripens in these high-elevation arid regions is prized in the market for the high sugar content. However, fruit production in these conditions can be challenging.

One major regional challenge is iron chlorosis that commonly occurs with stone fruits grown on arid alkaline soils (Alverez-Fernandez et al., 2003). A survey published in 1950 indicated that 23% of Utah orchards were affected by iron chlorosis (Thorne and Wann, 1950). With rapid urbanization in traditional fruit growing regions of the state, much of the production has since shifted to regions with more challenging soil conditions (Ernst et al., 2012; Whaley and Reeve, unpublished). Rootstocks differ in their adaptability to different soil conditions, and a major focus of the NC-140 project is to evaluate the adaptability of rootstocks to different fruit producing regions in North America.

Prunus interspecific hybrids and plum species have become a major focus of private and public rootstock breeding programs in Europe and North and South America, and are beginning to replace peach seedlings as preferred rootstocks for peach in some regions. Some of these hybrids appear to be more tolerant of alkaline (Egilla and Byrne, 1989; Mestre et al., 2015; Jimenez et al., 2011; Sotomayor et al., 2014) and saline (Doll et al., 2014; Zhou et al., 2018) soil conditions common to the Intermountain West. A multi-

[1] Utah State University, 4820 Old Main Hill, Logan, Utah 84322

[2] Department of Horticulture and Landscape Architecture, Colorado State University, Fort Collins, Colorado 80523

[3] Clemson University, 161 Poole Ag Center, Clemson, South Carolina 29634

[4] Utah State University Extension – Utah County, Orem, UT 84097

[1] brent.black@usu.edu

state study was established in 16 locations across the U.S. and Mexico to evaluate the compatibility and performance of newly commercialized *Prunus* rootstocks for peach, as part of the NC-140 Regional Project. The results across all locations have been published elsewhere (Reighard et al., 2018; 2020). Here we compare these rootstocks at the three locations in the Intermountain West region to determine those best suited to the region.

Materials and Methods

'Redhaven' peach budded to a series of rootstocks were planted in three orchard locations in 2009. The locations included one experimental orchard in Colorado, and both an experimental and a commercial orchard in Utah (Table 1). All three orchards are considered high-elevation peach production sites, with elevations exceeding 1300 m. Soil pH ranged from 7.5 to 8.5. The UT-Kaysville (UTK) site is a research farm operated by the Utah State University Agriculture Experiment Station and features the lowest soil pH of the three locations. Iron chlorosis is not typically a management concern for peaches at this location. The site in West Payson, UT (UTP) is on a commercial fruit farm that is prone to iron chlorosis, and standard management for this location is annual applications of chelated iron. However, iron was not supplemented on this planting. The Colorado (CO) site is also a research farm in Grand Junction (Western Colorado Research Center) operated by the Colorado State University Agriculture Experiment Station. The rootstock cultivars included seven interspecific *Prunus* hybrids and three *Prunus* species in addition to six *P. persica* rootstocks (Table 2).

Each trial was planted as a randomized complete-block design with eight replicates of single-tree plots of each rootstock. The rootstock 'Imperial California' was not included at the UTP location. Although 'Controller™ 7' was planted at this location, data collection for this rootstock was discontinued due to high mortality in the first two years. With the exception of withholding iron chelate applications, orchards received standard cultural practices for each location and were irrigated according to local conditions. General rootstock performance indicators including tree size, yield, yield efficiency, root sucker number, bloom date and fruit size were collected at each location, and are published elsewhere (Reighard et al., 2018; 2020) along with performance at 9 additional locations throughout North America. Here we report on the adaptability of these rootstocks to high-elevation sites with alkaline soil conditions.

Tree size was determined annually by

Table 1. Locations and characteristics of three experimental orchard sites where rootstocks were tested in the Intermountain West region of the U.S.

Location	Soil type	pH	Clay (%)	O.M. (%)	Elevation, Latitude	Slope, Aspect
Kaysville, Utah	Kidman fine sandy loam	7.5	13	1.7	1336 m, 41º01'15" N	1 to 3%, W
West Payson, Utah	Hiko Peak stony sandy loam	8.5	14	0.75	1445 m, 40º07'49" N	8 to 15%, N
Grand Junction, Colorado	Turley clay loam	8.3	30	1.3	1450 m, 39º02'35" N	0 to 2%, N

Table 2. Rootstock cultivars compared in the 2009 NC-140 trial at three Intermountain West sites and their reported species composition.

Rootstock cultivar	Species
Lovell	*Prunus persica*
Guardian®	*P. persica*
KV-010123	*P. persica*
KV-010127	*P. persica*
Controller™ 8 (HBOK 10)	*P. persica*
[1]Controller™ 7 (HBOK 32)	*P. persica*
Bright's Hybrid #5 (BH-5)	*P. dulcis x P. persica*
Krymsk® 86 (Kuban 86)	*P. cerasifera x P. persica*
Controller™ 5 (K146-43)	*P. salicina x P. persica*
Atlas	*P. persica x* (*P. dulcis x* (*P. cerasifera x P. mume*))
Viking	*P. persica x* (*P. dulcis x* (*P. cerasifera x P. mume*))
Prunus americana	*P. americana*
Empyrean® 2 (Penta)	*P. domestica*
[2]Imperial California	*P. domestica*
Rootpac® R (Replantpac)	*P. cerasifera x P. dulcis*
Krymsk® 1 (VVA-1)	*P. tomentosa x P. cerasifera*

[1]Initially included at all three locations, but 100% mortality at UTP.
[2]Not included in the UTP location.

measuring trunk circumference, and trunk cross-sectional area (TCSA) calculated from trunk circumference. Relative leaf chlorophyll was measured periodically at the UTP orchard using a handheld chlorophyll content meter (CCM-200, Opti-Sciences, Inc. Hudson, NH). The CCM and other instruments designed to provide *in situ* measurements of leaf chlorophyll are influenced by the optical properties of the leaf (Parry et al., 2014), which vary among species, and even among cultivars within a species. Over the range of measurements reported here, the chlorophyll content index (CCI) tends to be more linearly related to actual leaf chlorophyll than SPAD meters that are the other predominant optical measurement. However, converting to actual leaf chlorophyll content requires species-specific calibration and we are unaware of any peach-specific calibration, so CCI values are presented as a relative leaf chlorophyll content. Relative leaf chlorophyll was determined on leaves selected from the mid shoot of current season growth, at mid-canopy height, with values based on the measurement of at least 3 leaves per tree. Leaf chlorophyll measurements were also taken at the UTK location in the first few years of the experiment, but there were no differences among rootstocks at this location, and data collection was discontinued.

Final tree size across the three locations was analyzed using a mixed model with replication as a random factor and site and rootstock as fixed factors. Compound symmetry covariance structure on residuals were used to account for the correlation among observations within the same site. Rootstocks that were not present in at least two of the locations were excluded from the analysis.

Although chlorophyll measurements were taken several times per year at the UTP site, measurements taken in mid-July represented the most complete data set for the 10-year study. July chlorophyll data were analyzed as a mixed model with block treated as a random effect and rootstock, year, and rootstock × year treated as fixed effects. Heterogeneous compound symmetry covariance structure was used for the multiple year repeated measures analysis.

Pairwise comparisons of least square means were made as needed and were adjusted for multiplicity using Tukey-Kramer's method. All analyses were performed using PROC MIXED of SAS/STAT (version 15.1, SAS Institute Inc., Cary, NC, USA). Significance level is specified at the 0.05 level.

Results and Discussion

The three Intermountain West locations used for this study provide the opportunity for useful comparisons. The locations are at similar elevation and latitude, resulting in similar climatic conditions, but differ in soil texture and pH. Tree growth, as measured by TCSA, showed significant location × rootstock interactions, and was analyzed independently by location (Table 3). The largest trees were at UTK with overall average of 153 cm^2 TCSA. Although smaller than trees at UTK, size at the other two locations was similar (overall mean of 83.8 and 83.1 cm^2 TCSA for UTP and CO, respectively).

Table 3. Final tree size based on trunk cross-sectional area (TCSA, cm2) at 30 cm above the graft union, measured after the 2017 growing season. Rootstocks are sorted in order of descending size at the Kaysville (least alkaline) site.

Rootstock	UT-Kaysville	UT -West Payson	Colorado
Viking	213.6 a	106.7 abcd	115.5 abc
Bright's Hyb.5	204.7 ab	153.1 a	125.2 ab
Krymsk ®86	186.2 ab	95.6 bcde	89.9 abcdef
Lovell	183.9 ab	63.6 fgh	85.0 bcdef
Guardian®	177.7 ab	76.0 defg	111.4 abc
KV-010127	176.9 ab	77.4 cdef	93.5 abcde
Imperial Cal.	176.2 ab	--	101.6 abcd
Atlas	174.5 ab	122.4 ab	130.1 a
KV-010123	157.6 ab	52.3 ghi	68.1 defg
Controller™ 8	154.2 ab	43.5 i	65.2 efg
Empyrean® 2	147.1 abc	100.8 bcd	77.0 cdef
Controller™ 7	144.1 bc	--	82.3 bcdef
P. americana	100.2 cd	67.1 efgh	48.4 ghi
Rootpac® R	97.0 d	111.8 abc	61.3 fgh
Controller™ 5	84.5 d	46.2 hi	42.1 hi
Krymsk® 1	74.8 d	56.0 fghi	33.6 i

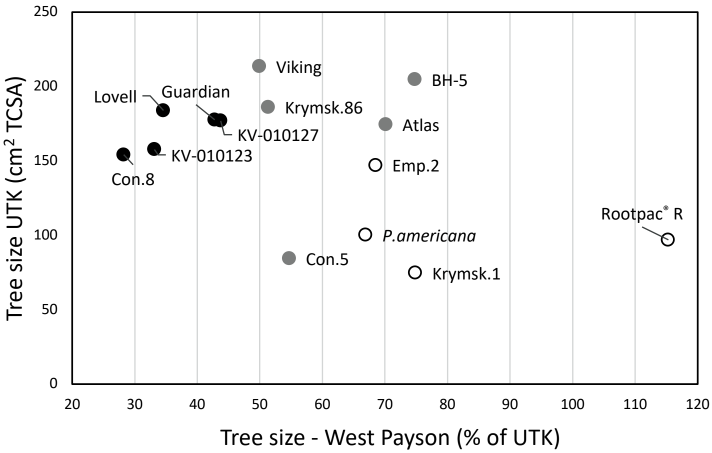

Figure 1. Trunk cross-sectional area of 14 rootstocks at UT-West Payson relative to tree size at UT-Kaysville (UTK). Data symbol shade indicates genetic background of *P. persica* (black), hybrid (gray) and other species (white).

The industry standard rootstock Lovell resulted in the 4th largest trees at UTK but did not differ significantly from trees produced on 'Viking', the largest trees at that location. At CO, trees on Lovell were intermediate in size and differed significantly from trees on the largest ('Atlas') and smallest (*P. americana*, 'Controller™ 5' and 'Krymsk® 1') rootstocks. At the UTP location, Lovell was among the smallest rootstocks, with only weak-growing trees on 'Controller™ 8' being significantly smaller.

One way to visually illustrate tolerance to a challenging environment (whether it be soil conditions or disease pressure) is to compare overall growth of a genotype in that environment to that of growth in a non-challenge environment. Fig. 1 illustrates this comparison for UTP where the Y-axis shows tree size at a less challenging location

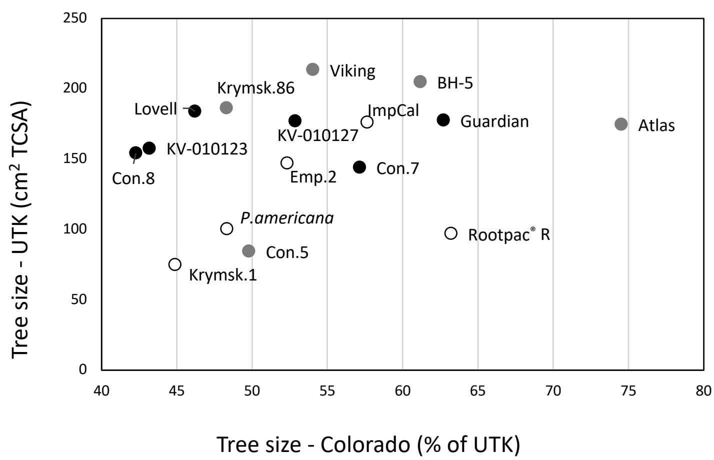

Figure 2. Tree size at the Colorado location (alkaline, high clay content) relative to tree size at the least alkaline UT-Kaysville site.

(UTK), and the X-axis is tree size at a more challenging location (UTP). In this case, the tree size at UTP is expressed as a percent of size at UTK. Rootstock genotypes that are most tolerant of the challenge conditions would separate along the Y-axis (based on relative vigor) but would cluster near 100% along the X-axis. Based on this analysis, the rootstocks most tolerant of the alkaline conditions at UTP were 'Rootpac® R', 'Krymsk® 1', 'Bright's Hybrid #5', 'Atlas' and 'Empyrean® 2', which all had size at least 65% that of the same rootstock at UTK. Interestingly, 'Rootpac® R' trees grew better at UTP than at UTK. However, based on results from other locations across the U.S., the 'Rootpac® R' trees were much smaller at UTK and not disproportionately larger at UTP. Averaged across all participating NC-140 locations, 'Rootpac® R' was most similar in size to 'Bright's Hybrid #5' and Lovell (Reighard et al., 2020), whereas 'Rootpac® R' at UTK was among the smallest rootstocks (Table 3).

Based on tree growth, the rootstocks most tolerant of conditions at CO were 'Atlas', 'Rootpac® R', Guardian® and 'Bright's Hybrid #5'; whereas the least tolerant were 'Controller™ 8', KV-010123, 'Krymsk® 1' and Lovell (Fig. 2). Tree growth at CO relative to UTK did not show the same correlation with genetic background, where *P. persica* Guardian® was among the more tolerant, and 'Krymsk® 1' (*P. tomentosa x P. cerasifera*) was among the least tolerant.

Measurements of relative leaf chlorophyll content are useful to compare tree health, and particularly tree N and Fe status. These measurements generally quantify the visible differences in leaf color, where healthy vigorous peach leaves typically have CCI values >20, and leaves with pronounced visible chlorosis have values <15. Measurements taken at the UTP location in July of each year (except 2012) were compared to determine propensity for iron chlorosis (Table 4). Measurements earlier in the season are typically a function of spring weather conditions, where cold rainy conditions delay leaf greening across all rootstocks (data not shown). Except for extreme cases where trees are going into decline, the symptoms later in the season tend to show less pronounced differences among rootstocks. There were significant differences among rootstocks in each year except in 2017, when all of the values were relatively low. In years where there were rootstock differences, 'Bright's Hybrid #5' and 'Rootpac® R' consistently had the highest relative leaf chlorophyll content. Except for the first two seasons, 'Empyrean® 2' also ranked among the highest in leaf CCI. The *P. persica* rootstocks 'Controller™ 8', KV-010123, Lovell, Guardian® and KV010127 consistently ranked lowest in relative chlorophyll content.

Relative leaf chlorophyll was not measured at the CO location. However, visual ratings were made in the third year of the planting and were published previously (Pokharel and Reighard, 2015). Their observations were consistent with our findings at the UTP site where the lowest levels of chlorosis were for 'Viking', 'Atlas', Guardian®, and 'Rootpac® R' (referred to as Mirobac by Pokharel and Reighard, 2015). Conversely, they noted the highest levels of chlorosis were for the rootstocks 'Controller™ 7' (HBOK 32), KV-010123, KV-010127 and 'Controller™ 8' (HBOK 10).

Conclusions

Results from this study concur with previous research on *Prunus* rootstocks indicating that tolerance to alkaline soils is greater in species other than *P. persica*. This genetic effect was most pronounced at the UTP location. As was mentioned above, the growth of *P. persica* selections at CO was not consistently less than other genotypes as was noted for UTP. The reason for this is not clear. As noted previously, general tree vigor was similar at the CO and UTP sites. Differences in tolerance may have been due to adaptability to soil texture. The soil at

Table 4. Relative leaf chlorophyll in mid-July at the West Payson (UTP) site measured with a chlorophyll content meter (OptiScience CCM-200). Units are chlorophyll content index. Values are based on measurements of at least 3 leaves selected on the mid-shoot of current season growth on each replicate tree. Measurements were not made in July 2012.

Rootstock	2010	2011	2013	2014	2015	2016	2017
Bright's Hyb.5	19.2 a	18.8 a	19.5 a	16.3 abc	14.1 ab	23.0 abc	14.2 a
Rootpac® R	17.9 a	18.6 ab	19.9 a	16.8 ab	14.0 abc	23.8 a	11.6 a
Controller™ 5	18.9 ab	16.7 abcd	19.5 a	15.2 abcd	11.6 abc	22.0 abcd	13.9 a
Empyrean® 2	15.4 bc	14.1 bcd	18.1 ab	17.8 a	15.8 a	23.4 ab	12.7 a
Krymsk® 86	16.5 abc	15.9 abcd	19.5 a	14.7 abcd	11.7 abc	22.0 abcd	14.2 a
Atlas	16.6 abc	15.4 abcd	17.1 abcd	14.7 abcd	12.1 abc	21.3 abcd	10.4 a
Krymsk® 1	16.4 abc	15.1 abcd	17.7 ab	15.4 abcd	8.0 bc	20.5 abcde	13.1 a
P. americana	16.1 abc	11.7 d	17.2 abc	14.7 abcd	11.8 abc	22.0 abcd	12.5 a
Viking	17.3 abc	17.0 abc	15.1 bcde	12.6 bcd	11.3 abc	19.1 a-f	10.8 a
KV-010127	14.8 bc	13.1 cd	15.1 bcde	14.2 abcd	9.0 bc	17.8 cdef	10.4 a
Guardian®	14.9 bc	11.3 d	14.4 cde	11.2 d	7.4 bc	18.4 b-f	10.6 a
KV-010123	13.7 c	12.0 d	14.1 de	11.7 cd	8.4 bc	17.1 def	10.4 a
Lovell	15.0 bc	12.1 d	12.3 ef	10.8 d	7.3 c	15.3 ef	10.9 a
Controller™ 8	13.9 c	11.8 d	9.8 f	13.2 abcd	9.0 bc	15.1 f	10.2 a

CO had a much higher clay content than at the other two locations (Table 1). Whether these differences were related to clay soil tolerance or some other factor needs further investigation.

Acknowledgements

The authors gratefully acknowledge the technical assistance of Thor Lindstrom and Andrew Swain. We also thank Bailey Nurseries, Inc. (Newport, Minnesota), and Fowler Nursery (Newcastle, California) for propagating trees. Funding for this research was provided by USDA/NIFA (Washington, D.C.) through the Multi-State NC-140 project "Improving Economic and Environmental Sustainability in Tree-Fruit Production through Changes in Rootstock Use" and by the Utah and Colorado Agricultural Experiment Stations. This paper is approved as Utah Agricultural Experiment Station paper number 9280.

Literature Cited

Alvarez-Fernandez, A., P. Paniagua, J. Abadia and A. Abadia. 2003. Effects of Fe deficiency on yield and fruit quality in peach. J. Agric. Food Chem. 51: 5738-5744.

Doll, D.A., R.A. Duncan, L. Hendricks and W. Micke. 2014. Performance of six almond rootstocks with long-term exposure to sodium and chloride. Acta Hort. 1028: 273-278.

Egilla, J.N. and D.H. Bryne. 1989. The search for peach rootstocks tolerant to alkalinity. Fruit Var. J. 43(1): 7-11.

Ernst, T., S.D. Rowley, B.L. Black and T.R. Roper. 2012. Reviewing potential local fruit markets: A Utah case study. J. Amer. Pom. Soc. 66(1):16-22.

Jimenez, S., J. Pinochet, J. Romero, Y. Gororcena, M.A. Moreno and J. L. Espada. 2011. Performance of peach and plum based rootstocks of different vigour on a late peach cultivar in replant and calcareous conditions. Scientia Hort. 129: 58-63.

Mestre, L., G. Reig, J.A. Betran, J. Pinochet and M.A. Moreno. 2015. Influence of peach-almond hybrids and plum-based rootstocks on mineral nutrition and yield characteristics of 'Big Top' nectarine in replant and heavy-calcareous soil conditions. Scientia Hort. 192: 475-481.

NASS, 2019. Noncitrus fruits and nuts: 2018 Summary. USDA National Agricultural Statistics Service. ISSN: 1948-2698.

Parry, C., J.M. Blonquist and B. Bugbee. 2014. *In situ* measurement of leaf chlorophyll concentration: analysis of the optical/absolute relationship. Plant, Cell Environ. 37:2508-2520.

Pokharel, R.R. and G.L. Reighard. 2015. Evaluation of rootstock effect on tolerance to iron chlorosis and cytospora canker in peaches. Acta Hort. 1084: 159-163

Reighard, G.L., W. Bridges, Jr., D. Archbold, A. Atucha, W. Autio, T. Beckman, B. Black, D. Chavez, E. Coneva, K. Day, M. Kushad, R.S. Johnson, T. Lindstrom, J. Lordan, I. Minas, D. Ouellette, M. Parker, R. Pokharel, T. Robinson, J. Schupp, M. Warmund, and D. Wolfe. 2018. Rootstock performance in the 2009 NC-140 peach trial across 11 states. Acta Hort 1228:181-186.

Reighard, G., W. Bridges, Jr., D. Archbold, A. Atucha, W. Autio, T. Beckman, B. Black, D. Chavez, E. Coneva, K. Day, M. Kushad, P. Francescatto, M. Kushad, R.S. Johnson, T. Lindstrom, J. Lordan, I. Minas, D. Ouellette, M. Parker, R. Pokharel, T. Robinson, J. Schupp, M. Warmund, and D. Wolfe. 2020. Nine-Year Rootstock Performance of the NC-140 'Redhaven' Peach Trial across 13 States. J. Amer. Pom. Soc. 74(1): 45-56.

Sotomayor, C., R. Ruiz and J. Castro. 2014. Growth, yield and iron deficiency tolerance level of six peach rootstocks grown on calcareous soil. Ciencia e Investigacion Agraria. 41(3): 403-409.

Thorne, D.W. and F.W. Wann. 1950. Nutrient deficiency in Utah orchards. Utah State Agr. College Bul. 1950.

Zhou, S., R. Walker and E. Edwards. 2018. Better tree performance and water use efficiency through resilient root systems: rapid screening for drought and salinity stress tolerance using relative growth rate. Acta Hort. 1219: 151-156.

Correction:

In the hard copy version of the of volume 74, issue 5 of the Journal, the authorship and acknowledgements are incorrect and should be:

SHENG YANG[1], MUDAN BAI[1], GUOWEI HAO[1], XIAOWEI ZHANG[1], HUANGPING GUO[1]*, BAOCHUN FU[1]*, and LIULIN LI[2]*

[1] Pomology Institute, Shanxi Agricultural University, Shanxi Key Laboratory of Germplasm Improvement and Utilization in Pomology, Taiyuan, Shanxi, 030031, China; E-mail: ys20080808@163.com

[2] College of Horticulture, Shanxi Agricultural University, Taigu, Shanxi, 030801, China; E-mail: tgliulin@163.com

Acknowledgments: The author is grateful to LI Liu-lin, FU Bao-chun and GUO Huang-ping, for his/her help in manuscript preparation. This work was partially supported by the China Agriculture Research System (CARS-28-28), The Doctoral Scientific Fund Project of Shanxi Academy of Agricultural Sciences (YBSJJ1709), The Research Subject of Agricultural Science and Technology Innovation of Shanxi Academy of Agricultural Sciences (YCX2018D-2YS14), Shanxi Province Natural Science Foundation (201801D121255), The Project of Scientific and Technological Innovation research of Shanxi Academy of Agricultural Sciences (YCX2020SJ10).