Growth and Yield of ‘Budousanshou’ Grafts on ‘Fuyuzanshou’ and ‘Karasuzanshou’ Rootstocks

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The growth and yield of ‘Budousanshou’ (*Zanthoxylum piperitum* (L.) DC. f. *inerme* Makino) trees were compared between grafts on ‘Fuyuzanshou’ (*Z. alatum* Roxb. var. *planispinum* Rehd. et Wils.) seedlings and ‘Karasuzanshou’ (*Fagara ailanthoides* Engl.) seedlings. Comparisons were made for 8 years after transplanting. The tree height for grafts on ‘Karasuzanshou’ rootstock was greater than for ‘Fuyuzanshou’ grafts throughout the experimental period after transplanting. For both graft treatments, tree height did not increase beyond 6–7 years after transplanting, suggesting that the trees had reached maturity. In addition, the canopy volume of grafts on ‘Karasuzanshou’ rootstock was greater than that on ‘Fuyuzanshou’ rootstock at 2 years after transplanting. The yield per tree and canopy volume were higher for grafts on ‘Karasuzanshou’ than grafts on ‘Fuyuzanshou’ rootstock by 7 years post-transplanting (i.e., the mature stage). Due to its greater canopy volume, the per tree yield of mature ‘Karasuzanshou’ grafts has the potential to be greater than that from ‘Fuyuzanshou’; therefore, ‘Karasuzanshou’ is a good candidate rootstock for the effective production of Japanese peppers.

Key Words: canopy volume, cumulative yield, number of fruit clusters, tree height.

Introduction

In Wakayama Prefecture, Japan, Japanese pepper (*Zanthoxylum piperitum* (L.) DC.) has been cultivated for many years, and the region is the highest producer of this plant in Japan (Naito, 2004). Wakayama Prefecture mainly grows the ‘Budousanshou’ variety, which is derived from ‘Asakurasanshou’ (*Z. piperitum* (L.) DC. f. *inerme* Makino), a common commercial pepper variety. The ‘Budousanshou’ variety is characterized by large crops, large fruit clusters, and fruits that are naturally fertile (Shinya, 2003). ‘Inuzanshou’ (*Z. schinifolium* Sieb. et Zucc.) seedlings are currently used as the primary rootstock for the production of Japanese pepper in Wakayama Prefecture. However,

grafts on ‘Inuzanshou’ have high mortality rates for several years after transplanting. Another rootstock, seedlings of ‘Fuyuzanshou’, which is a more vigorous relative of Japanese pepper, has been commonly used since its introduction in the 1990s. Previously, we reported (2005) that grafts on ‘Karasuzanshou’ seedlings that were growing vigorously in native coastal regions of Wakayama Prefecture exhibited lower mortality rates. Compared to ‘Fuyuzanshou’ rootstock, the canopy volume on ‘Karasuzanshou’ seedlings doubled within 5 years after transplanting (Maeda et al., 2005). The use of vigorous rootstocks improves the survival rate of young trees. To increase profitability, yield must also be improved. The present study evaluated the impact of cultivation without pruning on the growth and yield of the Japanese pepper ‘Budousanshou’, grafted onto either ‘Fuyuzanshou’ or ‘Karasuzanshou’ rootstock over an 8-year period, with data collection beginning immediately after transplanting.

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Materials and Methods

Plant materials and growth conditions

One-year-old ‘Budousanshou’ trees grafted onto either ‘Fuyuzanshou’ or ‘Karasuzanshou’ seedling rootstocks were used in this study. Eight trees were grown on each type of rootstock. Young trees were transplanted at a density of 250 plants/10 a (2 m ridge $\times$ 2 m spacing) in December 2003 in Shirahama, Wakayama Prefecture, Japan. Prior to transplanting, all trees were cut back to a height of 0.5 m. Nitrogen fertilizer was applied once each May at an annual rate of 35 kg·ha⁻¹ during the first 2 years after transplanting and then increased to an annual rate of 150 kg·ha⁻¹ with two applications in May and September, starting in the third year when the trees began to bear fruit. Appropriate irrigation was provided. The trees were left unpruned throughout the experiment and were allowed to bear fruit starting 3 years after transplanting.

Parameter measurements

1. Tree height and canopy volume: Tree height and canopy volume were measured yearly for each tree. Canopy volume was calculated in December using the following equation: $0.7 \times \text{long diameter} \times \text{short diameter} \times \text{height}$ (Norinsuisansho-kajushikenjo-okitsushijo, 1987).
2. The trunk cross-sectional area (TCSA) of rootstock and scion parts: TCSA (10 cm above the grafted union for trunk girth; 10 cm below the graft union for rootstock girth) was measured, and the ratio of the TCSA of scion parts to the TCSA of rootstock parts was calculated.
3. Yield and number of fruit clusters: Fruits were harvested from every fruit cluster beginning in mid-May. Total fruit yield, the number of fruit clusters per tree, and canopy volumes were determined. Harvesting was performed when the fruits were about 3 mm.

Results and Discussion

The 8-year investigation revealed that Japanese pepper plants, ‘Budousanshou,’ grafted onto ‘Karasuzanshou’ rootstock were significantly taller than individuals grafted onto ‘Fuyuzanshou’ (Fig. 1). The Japanese peppers matured 7 or 8 years after transplanting and grew to 3 m in height (Naito, 2004). In this investigation, the grafts on ‘Karasuzanshou’ rootstock had reached an average height of 3.1 m by 8 years after transplanting, whereas the grafts on ‘Fuyuzanshou’ were shorter, reaching an average height of 2.3 m by 8 years after transplanting.

The long diameter of the canopies did not differ significantly between the two rootstocks (Fig. 2). For both graft treatments, the long diameter exceeded the 2 m plant spacing by 5 years after transplanting.

At 4 years after transplanting, the grafts on ‘Karasuzanshou’ had a significantly greater canopy volume than the grafts on ‘Fuyuzanshou’ (Fig. 3).

Fig. 1. Effect of rootstocks on tree height in ‘Budousanshou’. Vertical bars indicate SE (n=8). * and NS: significance at $P=0.05$ and non-significance by t -test, respectively.

Fig. 2. Effect of rootstocks on long diameter of canopy in ‘Budousanshou’. Vertical bars indicate SE (n=8). NS: non-significance by t -test.

Fig. 3. Effect of rootstocks on canopy volume in ‘Budousanshou’. Vertical bars indicate SE (n=8). * and NS: significance at $P=0.05$ and non-significance by t -test, respectively.

However, canopy volume at 5 years after transplanting and thereafter did not significantly differ between rootstock species. This lack of a difference may have been due to the shading of leaves and branches by neighboring trees. The canopies of some trees continued to increase and their branches had reached adjacent tree canopies by 5 years after transplanting. More space may be required to accommodate canopy volume growth, and pruning of 'Budousanshou' trees after 5 years, post-transplanting, may be necessary.

The rootstock TCSA of grafts on 'Karasuzanshou' was greater than that of grafts on 'Fuyuzanshou', and the difference increased with age (Fig. 4). Scion TCSA did not significantly differ between the two rootstocks except during the first 2 years. The ratio of scion to rootstock TCSA ranged from 0.3 to 0.5 for 'Karasuzanshou' and from 0.5 to 0.7 for 'Fuyuzanshou' (Fig. 4). Throughout the experimental period, the scion to rootstock TCSA ratio was significantly lower for grafts on 'Karasuzanshou', highlighting its vigorous nature as a rootstock. With respect to rootstock overgrowth and undergrowth, this result is contradictory to a previous result for rootstocks of citrus and the cause is unknown. Tree vigor (tree height and canopy volume) increased with 'Karasuzanshou' with no difference in the scion TCSA between the two rootstocks, and only the rootstock TCSA was large. Hydraulic conductance may be a possible cause. In recent years, the relationship of tree vigor and hydraulic conductance has become clear. Ogata

et al. (1994) showed a positive relationship between tree vigor and hydraulic conductance using various citrus rootstocks. Moreover, Muramatsu and Hiraoka (2008) obtained the same results with various kinds of fruit trees. Yonemoto et al. (2004) reported a decline in hydraulic conductance and in the tree vigor of scions that used trifoliate orange rootstock with 'Flying Dragon' trifoliate orange as an interstock. The possibility exists that the hydraulic conductance in 'Karasuzanshou' rootstock, which showed higher TCSA, is greater. In the future, we would like to verify this hypothesis.

The number of fruit clusters per tree increased at almost the same rate in both graft treatments between 3 and 6 years after transplanting and then increased at a higher rate in grafts on 'Karasuzanshou' beginning 7 years after transplanting (Fig. 5). The number of fruit clusters reached 3300 for grafts on 'Karasuzanshou' at 8 years post-transplanting, which was more than double the 1500 fruit clusters found on 'Fuyuzanshou'. The number of fruit clusters per canopy volume was also greater for grafts on 'Karasuzanshou' at 7 years after transplanting, but this tendency was not apparent at ages up to 6 years (Fig. 5).

For both graft treatments, the yield per tree increased at the same rate from 4 to 6 years after transplanting. The yield continued to increase at the same rate in grafts on 'Karasuzanshou', reaching 4 kg by 8 years after transplanting; however, after 7 years, the yield declined on 'Fuyuzanshou'. The yield of 'Fuyuzanshou' grafts had peaked at 2.5 kg by 6 years after transplanting. The yield per canopy volume was also greater for grafts on

Fig. 4. Effect of rootstocks on TCSA of rootstock (A), TCSA of scion (B), and the ratio of the TCSA of scion to the TCSA of rootstock (C) after transplanting 'Budousanshou'. Vertical bars indicate SE (n=8). * and NS: significance at $P=0.05$ and non-significance by t -test, respectively.

Fig. 5. Effect of rootstocks on number of fruit clusters per tree (A) and number of fruit clusters per canopy volume (B) in 'Budousanshou'. Vertical bars indicate SE (n=8). * and NS: significance at $P=0.05$ and non-significance by t -test, respectively.

Fig. 6. Effect of rootstocks on yield per tree (A) and yield per canopy volume (B) in 'Budousanshou'. Vertical bars indicate SE (n = 8). * and NS: significance at $P=0.05$ and non-significance by t -test, respectively.

'Karasuzanshou' by 7 years after transplanting, but no difference was found between grafts during the first 4 years (Fig. 6). The yield of mature trees reportedly peaks at 8–12 kg per tree in 10-year-old trees (Naito, 2004), which is higher than the present result. Two possible reasons may explain this discrepancy. One involves the developmental stage of the harvested seeds: mature seeds are heavier than immature seeds, and the seeds harvested in this experiment were immature. The other involves tree form: trees that have spreading crowns like 'Asakurasanshou,' a common commercial pepper variety, grow upright. In contrast, in trees that extend their branches laterally, like 'Budousanshou' (the present study plant), shade from leaves and branches can reduce field productivity. No difference was observed in the tree forms between the two graft treatments. However, the canopy volume of grafts on 'Karasuzanshou' rootstock tended to be greater than on 'Fuyuzanshou'. Because the vigor of grafts on 'Karasuzanshou' rootstock was strong, the trees grew somewhat upright with little downward growth of tree branches compared to grafts on 'Fuyuzanshou'. Therefore, the yield of the 'Karasuzanshou' rootstock trees continued to increase throughout the experimental period. Pruning of the grafts on 'Fuyuzanshou' was considered to be necessary so that fruit clusters would not be shaded by leaves and branches.

The cumulative yield per tree was lower for grafts on 'Karasuzanshou' than for grafts on 'Fuyuzanshou' during the first 5 years, but then subsequently increased and reached 11 kg at 8 years after transplanting (Fig. 7). Fisher (1971) and Mizutani et al. (1985) reported that the use of dwarf rootstock resulted in precocity in apple and peach trees, meaning that the time to bearing age

Fig. 7. Effect of rootstocks on cumulative yield per tree in 'Budousanshou'.

was reduced. In this study, use of the vigorous 'Karasuzanshou' rootstock appears to have required a longer period of time to bear first fruit, but ultimately, use of this rootstock resulted in higher productivity. Because 'Karasuzanshou' rootstock produced high-vigor trees, young trees showed extensive vegetative growth. However, yield may have increased to convert energy into reproductive growth, in reaching maturity. Maeda et al. (2005) reported that the use of 'Fuyuzanshou' rootstock is advantageous in that it shortens the period required to reach a fruit-bearing age. However, 8 years after transplanting, when trees were considered to be mature, the yield of 'Karasuzanshou' rootstock had adequately increased.

Based on the above results comparing grafts on 'Fuyuzanshou' and 'Karasuzanshou', the latter achieved earlier canopy expansion under non-pruning conditions and showed a higher level of stable flowering. Consequently, grafts of 'Budousanshou' on 'Karasuzanshou' exhibited higher productivity after maturation, at 6 or 7 years after transplanting; thus, 'Karasuzanshou' appears to be a promising rootstock.

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