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RESEARCH ARTICLE

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The main factors causing "imperfect shell development" (ISD) in thin-shelled walnut

Abstract Effects of solar radiation, rainfall and cultivars on "imperfect shell development" (ISD) of the thin-shelled walnut were studied by means of field investigation and weather data comparison. The results showed that cultivars were the main factor causing the ISD of the thin-shelled walnut. Among the cultivars, Shangsong 6 was the most sensitive one, whose percentage of imperfect shell attained 67.3%, followed by Xiangling (52.7%). However, the rate of imperfect shells in Zhonglin 5 was only 20.9%. It was suggested that the main environmental factors contributing to the ISD of the thin-shelled walnut were sunlight intensity and rainfall during the shell-hardening stage.

Keywords walnut, shell, imperfect shell development (ISD)

1 Introduction

Walnut (*Juglans regia* L.) is native to China and an important frui crop for export. For a long time, China has been the leading walnut-producing country in the world. Since 1980s, a lot of new walnut cultivars have been developed which are early bearing, highly productive, thin-shelled and good in kernel quality. Moreover, those cultivars have been applied in production (Yang and Gao, 1996; Deng, 1999). However, it was found that many of the cultivars showed the ISD on the shell surface, such as roughly-dented patch, underdeveloped shell or even no shell formation with exposed kernel. Those defects influenced the external nut quality, storage capacity and commercial properties. The phenomenon is commonly known as ISD (Deng, 1999). Therefore, we studied the main factors causing the defect of thin-shelled walnut from 2003 to 2005.

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2 Materials and methods

2.1 Study sites and materials

The experiment was conducted in a hilly walnut orchard, belonging to the Lvling Fruit Co. Ltd. in Lincheng, Hebei Province, China. The orchard is situated at the eastern hilly areas of the southern Taihang Mountain with annual average sunlight of 2653 h, an annual average air temperature of 13°C, an extreme maximum temperature of 41.8°C, an extreme minimum temperature of −23°C, a frost-free period of 202 d and an annual rainfall of 521 mm.

Walnut trees were planted in 1999 and the cultivars included Xiangling, Yuanfeng, Liaoning 1, Zhonglin 5, and Shangsong 6. The planting density was 3 m × 4 m with a single-layer high open system. The yield per tree was approximately 5 kg without apparent alternative bearing.

2.2 Methods

During shell-hardening, 5 trees from each cultivar were randomly chosen and nuts from both the interior and exterior canopy were investigated, respectively. Meanwhile, an additional 5 trees were randomly selected and the developmental status of all the nuts was surveyed. In clear days, the light intensities at 10:00 and 16:00 were measured with a luminometer at different positions of a canopy with that in the open areas as the control. At each position, the intensity was measured three times, taking the average value and converting it into a relative intensity.

The meteorological data were collected from the Meteorological Bureau of the Lincheng County, three kilometers away from the orchard with the same altitude. The weather data included daily average temperature, rainfall time and amount, and solar radiation from June 1 to July 20 of 2003, 2004 and 2005, respectively.

From June 20 to July 20, 2006, gauze shading experiment was conducted with Xianglin. 1-, 2-, 4- and 8- layers

of gauze were put together for shading purposes with no shading as the control. The experiment was random-block designed with one tree serving as a plot. The treatment was repeated three times and for each plot, 100 nuts were evaluated.

2.3 Data analysis

Significant difference between treatments was statistically analyzed by means of *LSD* test or *t* test.

3 Results

3.1 Effect of different cultivars on ISD

In 2004, the status of shell development of different cultivars was surveyed and is shown in Table 1. It was indicated that a significant difference existed among different cultivars. Shangsong 6 reached the maximum percentage of 67.3%, very significantly higher than other cultivars. This was followed by Xiangling, Yuanfeng and Liaoning 1. Zhonglin 5 had the minimum percentage.

3.2 Effect of different positions of canopy on ISD

In 2004, the shell development of walnuts on different positions of the canopy was also surveyed and is shown in Table 2. It was indicated that the rate of ISD was lower for exterior nuts than interior ones and a similar tendency was followed by all the cultivars. Therefore, it was suggested that ISD was related to light conditions.

The relative light intensities on different positions of the canopy during shell-hardening are shown in Table 3. Whatever position was concerned, the light intensity was lower in the interior part than in exterior.

Correlative analysis shows that the rate of nuts with ISD was very negatively related to light conditions with the coefficient being 0.964. It was suggested that the light conditions during shell-hardening was the main factor influencing shell development.

3.3 Effect of different years on ISD

The shell development in different years is shown in Table 4. It was indicated that the status of shell development varied greatly with the years. For example, ISD in 2004 was very significantly higher than those in both 2003 and 2005. Therefore, it was inferred that the shell development of the thin-shelled walnut was associated with meteorological factors. The daily average temperature, rainfall and sun shining hours during the shell-hardening stage (June 5 to June 20) in 2003, 2004 and 2005 are shown in Table 5. It was clearly indicated that a very significant difference in these indices existed among the three years.

The correlation is shown in Table 6 between the main meteorological factors and imperfect shell development among different years. As shown in Table 6, the sunlight hours and air temperature during the shell-hardening stage were very negatively related to ISD, which was the main meteorological factor causing ISD. A positive correlation was found between rainfall and ISD, which was considered as the secondary factor affecting ISD in thin-shelled walnut.

Table 1 Shell development conditions of different walnut cultivars in 2004

type	Xiangling	Yuanfeng	Shangsong 6	Liaoning 1	Zhonglin 5
percentage of perfect shell/%	47.3C	62.4B	32.7D	64.1B	79.1A
percentage of imperfect shell/%	52.7B	37.6C	67.3A	35.9C	20.9D

Note: Data followed by the different small letters ($P < 0.05$) and capital letters ($P < 0.01$) means significant difference. The same as below.

Table 2 Shell development conditions of nuts in different positions on canopy in 2004

position	type	Xiangling	Yuanfeng	Shangsong 6	Liaoning 1	Zhonglin 5
interior	percentage of perfect shell/%	45.8	61.4	29.6	62.3	76.3
	percentage of imperfect shell/%	54.2	38.6	70.4	37.7	23.7
exterior	percentage of perfect shell/%	50.2	66.7	49.3	69.4	79.5
	percentage of imperfect shell/%	49.8	33.3	50.7	30.6	20.5

Table 3 Relative light intensity in different parts of canopy with different walnut cultivars (%)

cultivar	exterior part of the lower canopy	interior part of the lower canopy	exterior part of the middle canopy	interior part of the middle canopy
Xiangling	48.60	24.56	55.09	32.40
Yuanfeng	49.83	25.87	59.89	34.62
Shangsong 6	51.03	25.64	58.69	34.66
Liaoning 1	47.65	22.38	54.68	33.21

Table 4 Percentage of perfect shell development of different cultivars in different years

year	Xiangling	Yuanfeng	Shangsong 6	Liaoning 1	Zhonglin 5
2003	88.3A	91.4A	75.8A	95.6A	97.8A
2004	47.3B	62.4B	32.7B	64.1B	79.1B
2005	89.6A	94.3A	79.4A	96.7A	97.6A

Table 5 Weather data during walnut shell-hardening in different years

year	air temperature/°C	rainfall amount/mm·d^{-1}	hours of sunlight/h·d^{-1}
2003	27.6a	0.6B	8.3a
2004	24.5b	6.3A	6.5b
2005	27.6a	2.8B	8.8a

Table 6 Correlation between weather data during shell-hardening and the percentage of perfect shell development in different years

cultivar	air temperature	rainfall amount	hours of sunlight
Xiangling	0.9996**	−0.9132*	0.9836**
Yuanfeng	0.9966**	−0.8893*	0.9921**
Shangsong 6	0.9976**	−0.8952*	0.9904**
Liaoning 1	0.9996**	−0.9121*	0.9841**
Zhonglin 5	0.9999**	−0.9274*	0.9764**

Note: * means significantly correlated; ** means very significantly correlated.

Path analysis between different meteorological factors and ISD indicated that the main factors causing imperfect shell development were sunlight with the maximum path coefficient being −3.67, rainfall with the direct path coefficient being 2.85, followed by air temperature with a direct path coefficient being only 0.96. It was suggested that the main factor causing ISD was sunlight.

Table 7 Path coefficients of imperfect shell percentage as affected by main meteorological factors during shell-hardening stage

path coefficient	air temperature	rainfall amount	hours for sun shining time
direct path coefficient	0.96	2.85	−3.76
indirect path coefficient	−1.68	0.94	−0.48

3.4 Effect of sunlight intensity during shell-hardening on ISD

The rates of perfect shell development (PSD) of the Xiangling walnut treated with different shading are shown in Table 8. If the relative light intensity was lower than 50%, the rate of perfect shell development decreased very significantly. If it was lower than 20%, the rate of PSD decreased more severely, which supported that insufficient sunlight was responsible for ISD.

Table 8 Developmental status of nut shells with different shading treatments

item	control	1-layer gauze	2-layer gauze	4-layer gauze	8-layer gauze
relative light intensity/%	100	92.6	78.3	46.8	19.6
percentage of perfect shell/%	92.8A	91.2A	88.4A	48.4B	16.9C

4 Discussion

It is usually thought that the shell of walnut refers actually to the endocarp that would harden in the late stage of endocarp formation (Xiao et al., 1998). However, no concrete time has been determined. As for the study on ISD, no report has been found so far. In the present study, we suggested that the main factors were cultivars and sunlight intensity, and the adaptation to local conditions may be also involved. It has been found that the cultivars with higher rate of ISD are completely or partly of the Xinjiang-cultivar origin. For instance, Shangsong 6 (an offspring of the Xinjiang early-bearing walnut), Yuanfeng (an offspring of the Xinjiang early-bearing walnut), Xiangling (Shangsong 5 × A 9) and Liaoning 1 (Xingjiang Zhipi × Changli Dabopi) consistently contain the genetic genes of the Xingjiang walnut (Xi and Zhang, 1996; Liu and Chen, 1996). Perhaps the Xingjiang walnut has adapted to the excessive sunlight during shell-hardening in the long-term evolution and thus, when the sunlight is insufficient, the shell development is affected, which was proven by the experimental result in 2006. However, further studies on the mechanism of ISD influenced by sunlight intensity and the critical value of sunlight for occurrence of ISD are still required to be done in the future.

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