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RESEARCH ARTICLE

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The dynamics and correlation between nitrogen, phosphorus, potassium and calcium in a hazelnut fruit during its development

Abstract The dynamics and correlation between nitrogen, phosphorus, potassium and calcium were studied during the fruit development of three crossbreeds of hazelnut. The results showed that the young fruit rapid growth stage and kernel development stage were the critical periods for the absorption and accumulation of these mineral elements. With three crossbreeds, the content of nitrogen followed such a pattern that decreased in the initial stage, remained constantly in the middle stage and increased markedly in the late stage; phosphorus followed a slightly different pattern where it decreased in the initial stage, also remained constant in the middle stage, and first increased rapidly and then decreased rapidly in the late stage; potassium followed the pattern where it decreased mildly in the initial stage, increased gradually in the middle and late stages; calcium followed the pattern where it decreased sharply in the initial stage, remained constant in the middle and late stages. Nitrogen, phosphorus and potassium in fruits showed a significant or very significant positive correlation in the development course of hazelnut fruit and there was a dynamic equilibrium of coordination among the three elements.

Keywords hazelnut fruit, development, nitrogen, phosphorus, potassium, calcium, dynamics, correlation

1 Introduction

Hazel (*Corylus avellana* L.) belongs to the genus *Corylus* and the hazelnut is nutritious, has a high economic value, and can be used as an important raw material in the processing industry, such as various kinds of candy, ice cream and hazelnut milk (Ayter et al., 1986; Mitrovic et al., 1997; Chen, 2004). There is also a growing interest in evaluating hazelnut's role in a heart-healthy diet and several studies have proven a role for nuts to reduce coronary heart disease (Fraser et al., 1992; Hu et al., 1998; Durak et al., 1999; Sabaté et al., 2000). Researchers from many countries around the world pay much attention to its breeding, quality evaluation and selection of improved varieties (Guo et al., 2004), but there are few studies so far related to the dynamics of nutrition and minerals during nut development.

Ten kinds of elements are necessary for hazelnut growth and development, of which nitrogen, phosphorus, potassium and calcium are the most important ones. We conducted an in-depth study on the nitrogen, phosphorus, potassium and calcium contents in the development course of the hazelnut fruit, with a view to having a better understanding of the absorption, accumulation and nutrition dynamics of those elements in hazelnut fruit.

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2 Materials and methods

2.1 Materials

Materials were selected from Fruit Specimen Garden at the Liaoning Agricultural College, and three forms (strains) were 7-year-old crossbreeds of hazelnut (82–11, 84–237 and 84–402). Twenty one hazel trees of each strain were selected with a completely randomised block design. Every seven trees were treated as one block with three replicates. The trees were planted at a space of 2 m × 3 m and trained as a bundle-like shape.

2.2 Reagents and instruments

Sartorius electronic balance (accuracy 0.0001 g), Lambda25 uv-vis spectrophotometer (double beam, double monochromator, 1 nm fixed slit), KDY-9820 Kjeldahl instrument, JKXZ06-20A digestion furnace, HG-5 flame photometer.

The reagents used were analytically pure, produced by Beijing Chemical Reagent Factory; deionized water in the experiment was made by QJRO10 deionizing equipment.

2.3 Methods

Samples were collected at 4–7 day intervals when fruit first appeared. For each sampling, 50–100 fruits were selected randomly from different sections and directions of the tree canopy. Strain 1 (82–11) matured on August 17 and was sampled for ten times, strain 2 (84–237) matured on August 28 and was sampled for twelve times and strain 3 matured on September 1 and was sampled for thirteen times. After sampling, the fruit was placed in an ice bottle, and transferred to the laboratory as soon as possible. After the involucre was removed, the fresh weight of the fruit was measured immediately. Nuts were washed clean with deionized water and the enzymes were inactivated in an oven under 90°C for 15 mins and then cooled to 65°C for 24 h. The dry weight was measured, and the kernel was ground in a mill and saved for use. The nitrogen content was determined by the micro Kjeldahl method, phosphorus was determined by mixed acid digestion and Mo-Sb colorimetry method, potassium was determined by mixed acid digestion and flame photometry method, and calcium was determined by dry digestion permanganate titration method.

Nitrogen content was expressed in $g \cdot 100\,g^{-1}$ ($g \cdot 100\ g^{-1}$ fr.wt.), and phosphorus, potassium and calcium were expressed in $mg \cdot 100\,g^{-1}$ ($mg \cdot 100\ g^{-1}$ fr.wt.). By means of correlation analysis, the contents of the four elements were all expressed in $g \cdot 100\,g^{-1}$ ($g \cdot 100\ g^{-1}$ fr.wt.) The statistical analysis was conducted using the statistical package SPSS1310.

3 Results

3.1 Development pattern of hazelnut fruit

The hazelnut fruit development could be divided into seven phases: (1) Ovary expansion phase (from late May to June 13), the beginning of fruit development. (2) Young fruit rapid growth phase (from June 13 to July 8), young fruit size increased rapidly. (3) Shell hardening phase (from July 8 to July 17), shell began to harden till the shells fully hardened. (4) Kernel development phase (from July 17 to August 5), kernel volume increased remarkably. (5) Kernel filling phase (from August 5 to August 17), dry matter began to accumulate in the kernel. (6) Nut maturity phase (from August 17 to August 28), nut color changed from white to red or red brown. (7) Nut falling-off phase (from August 28 to September 1), matured nuts completely fell off naturally. The whole period can be roughly divided into three stages: initial stage (June 13–June 30), middle stage (June 30–July 17) and late stage (July 17–the end). There were two rapid growth stages, i.e., young fruit rapid growth stage and kernel development stage.

3.2 Nitrogen dynamics during the development of hazelnut fruit

The nitrogen content (Fig. 1) decreased in the initial stage, remained constant in the middle stage and increased markedly in the late stage. The content of nitrogen increased gradually during bud break, leaf expansion, flowering, shoot growth and fruit expansion (Lin et al., 2004). In the initial stage, as young fruit began to develop, nitrogen was consumed intensely with less accumulation, thus resulting in the constant decline of nitrogen content. In the middle stage, as cell divided promptly, young fruit volume expanded rapidly, but it was not the critical period for protein synthesis. The nutrition accumulation was

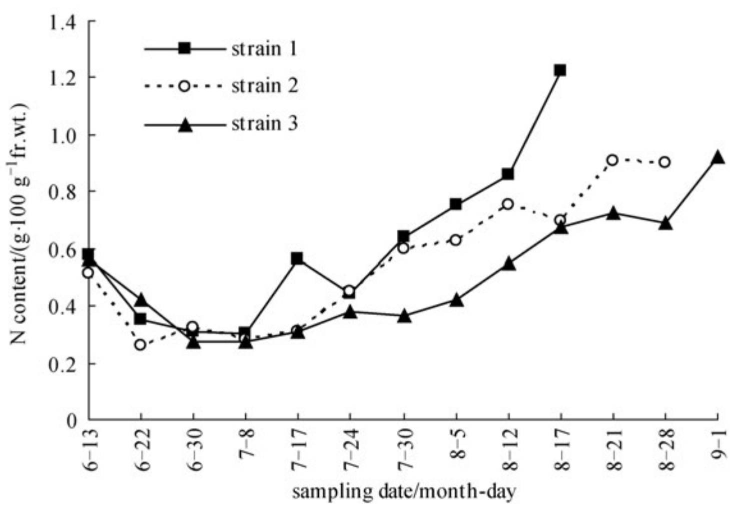

Fig. 1 Dynamics of nitrogen contents during the development of hazelnut fruit

accompanied by nutrition consumption, this stage was viewed as nutrition equilibrium phase (Dong, 1998). Except for strain 1, the nitrogen content was steady. In the late stage, as nitrogen content increased remarkably, the kernel developed rapidly and dry matter content increased markedly till the fruit matured.

3.3 Phosphorus dynamics during the development course of hazelnut fruit

Phosphorus content (Fig. 2) decreased in the initial stage, remained constant in the middle stage, and increased rapidly first and then decreased rapidly in the late stage. In the initial stage, young fruit developed rapidly and needed more phosphorus to participate in the synthesis of assimilation products (Qin et al., 1998), so that the content of phosphorus decreased. In the middle stage, as the fruit continued to expand and the shell began hardening, fruit had more phosphorus demands, but during this stage, the phosphorus absorption ability by the fruit was enhanced, so that phosphorus content was comparatively constant. With the development of fruit, kernel expanded remarkably and became replete in the fruit cavity, and the development of kernel needed abundant phosphorus (Liang et al., 2002), so there was a gradual increase of phosphorus accumulation, reaching a content peak.

The first great absorption occurred on July 24 with the contents of phosphorus being 87 $mg \cdot 100\ g^{-1}$, 89 $mg \cdot 100\ g^{-1}$ and 67 $mg \cdot 100\ g^{-1}$ in strain1, strain 2 and strain3, respectively. Afterwards, the contents of phosphorus demonstrated a significantly increasing trend and the absorption peak occurred at August 12 with the contents of phosphorus being 228 $mg \cdot 100\ g^{-1}$, 189 $mg \cdot 100\ g^{-1}$ and 149 $mg \cdot 100\ g^{-1}$ in strain1, strain2 and strain3, respectively. In the late stage, as the kernel development completed and fruit was ripe, the phosphorus absorption reduced and the preserved amounts had been massively consumed, thus the content of phosphorus decreased rapidly. Related studies demonstrated that, there exists a close relation between the phosphorus concentration dilution and the rapid increase in fruit weight during the same period (Liu et al., 2002).

3.4 Potassium dynamics during the development course of hazelnut fruit

Potassium was different from nitrogen and phosphorus in that it did not participate in the composition of organic matter, but it was an essential element in the fruit (Huang et al., 1993; Zheng, 1993; Gong, 2002). Potassium content (Fig. 3) decreased mildly in the initial stage and increased gradually in the middle and late stages. The decrease in the initial stage was caused by high consumption and less accumulation. The accumulation of potassium occurred mainly during the middle and late stages of fruit development. Moderate amount of potassium could enhance the fruit expansion and maturity and the potassium accumulation was in accordance with the nutrient demands during hazel fruit development (Liang et al., 2002).

In this stage, the content of potassium increased rapidly, which was likely related to the potassium stress reservation that played a significant role in promoting the fruit coloration and enhancing the fruit cell growth (Ma et al., 2004). According to Huang (1994), young fruit trees need less potassium but adult fruit trees need more because of flowering and fruiting. Whole-plant analysis of 16-year-old Golden Delicious apples confirmed that, among growth of all organs throughout the year, the content of potassium in ripening fruit accounted for 57.6% of the whole year potassium absorption amount in the whole plant. This confirmed that, during the early stage of growth, hazelnuts need a small amount of potassium while in the later stage of growth, they need a greater amount.

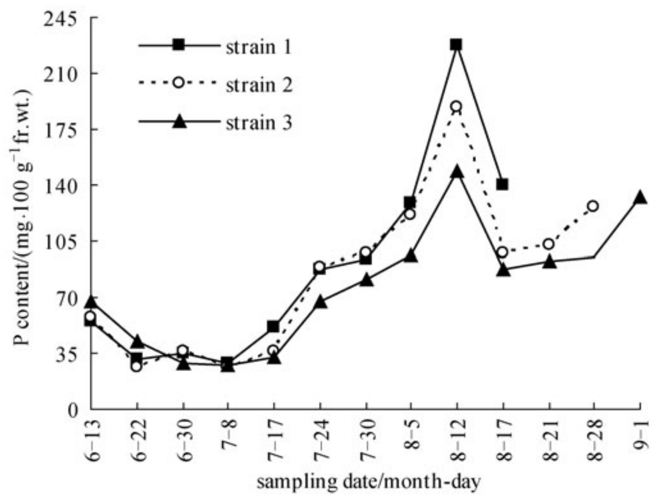

Fig. 2 Dynamics of phosphorus contents during the development course of hazelnut fruit

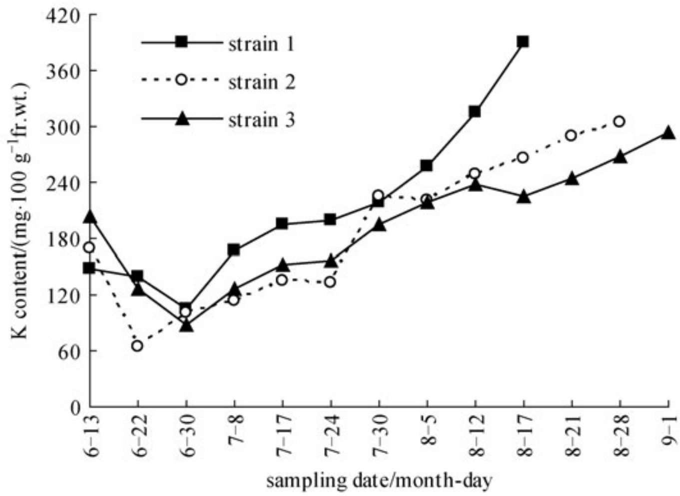

Fig. 3 Dynamics of potassium contents during the development course of hazelnut fruit

3.5 Calcium dynamics during the development course of hazelnut fruit

Calcium content (Fig. 4) decreased rapidly in the initial stage, comparatively steady in the middle and late stages. Because of its difficult movability, the absorption of calcium by plants occurred mainly in the young fruit rapid growth stage (Wang et al., 1994). During this period, cell division needed a comparatively higher level of calcium, which was closely related to metabolism and photosynthetic activity. In the metabolic activity, calcium acted as an enzyme activator. The initial stage was the critical period for calcium absorption and utilization in great amounts for the fruit. With the development and incessant expansion of young fruit, calcium was consumed greatly, and at the same time there was a dilution effect, resulting in a sharp decrease in its content.

Besides, there was a competition for calcium by the rapid growth of new shoots, and it was also an important factor that affected the calcium content variation (Fan et al., 1994). In the middle and late stages when fruit had comparatively low needs for calcium, as water content decreased gradually and dry matter accumulation increased, the content was constant with a slight increase.

3.6 Correlation analysis of nitrogen, phosphorus, potassium and calcium during the development course of hazelnut fruit

The correlation of the four elements was analyzed (Table 1) and the results indicated that nitrogen, phosphorus and potassium showed a significantly positive or very significantly positive correlation. This confirmed that during the development of hazel fruit, adequate supply of nitrogen, phosphorus and potassium was necessary and at

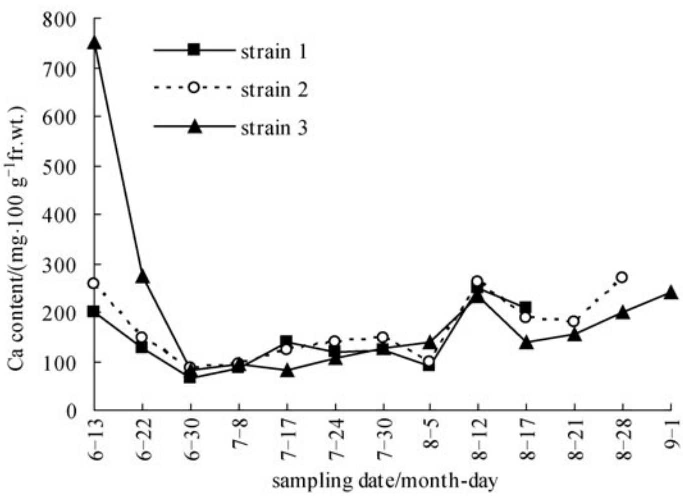

Fig. 4 Dynamics of calcium contents during the development course of hazelnut fruit

Table 1 The correlation of nitrogen, phosphorus, potassium and calcium during the development course of hazelnut fruit

hazel strains	elements	equations	*df*	*r*
1	N-P	$Y = 0.1676X - 0.013$	8	0.760^{*}
	N-K	$Y = 0.2966X + 0.0299$	8	0.955^{**}
	P-K	$Y = 1.1303X + 0.1091$	8	0.802^{**}
2	N-P	$Y = 0.1724X - 0.0116$	10	0.815^{**}
	N-K	$Y = 0.3317X + 0.0058$	10	0.971^{**}
	P-K	$Y = 1.2736X + 0.0825$	10	0.788^{**}
	N-Ca	$Y = 0.1857X + 0.0629$	10	0.653^{*}
	P-Ca	$Y = 0.7796X + 0.1003$	10	0.580^{*}
	K-Ca	$Y = 0.4997X + 0.071$	10	0.601^{*}
3	N-P	$Y = 0.138X + 0.0071$	11	0.728^{**}
	N-K	$Y = 0.2673X + 0.0601$	11	0.880^{**}
	P-K	$Y = 1.4004X + 0.0876$	11	0.874^{**}

Notes: X stands for the former element, Y stands for the latter element. * and ** represent significant differences at $P < 0.05$ and $P < 0.01$ respectively.

the same time hazelnut development needed a good balance and collaboration of the three elements. Our study showed that for the three strains, calcium showed a significantly positive correlation with nitrogen, phosphorus and potassium only in strain 2.

It was noteworthy that the significant correlation between these elements did not necessarily mean that there were obvious synergistic or antagonistic relations among them, whereas no correlation between the elements did not necessarily mean that they were completely irrelevant (Zou et al., 1985). The correlation between the elements could be the result of the effect of common environmental factors (Hou et al., 2002; Fang et al., 2005), and might also be due to that they were related to the basic structure and function of the cells (Charles, 1976). For example, calcium was the enzyme activator in metabolic activity, potassium was critical to the activity of some enzymes, and calcium could enhance the absorption of potassium significantly (Hou et al., 2002).

3.7 Content difference in nitrogen, phosphorus, potassium and calcium among strains

The contents of nitrogen, phosphorus, potassium and calcium in strain 1 were 1.224%, 140 $mg \cdot 100\ g^{-1}$, 391 $mg \cdot 100\ g^{-1}$ and 208 $mg \cdot 100\ g^{-1}$, respectively. In strain 2 the contents were 0.902%, 126 $mg \cdot 100\ g^{-1}$, 304 $mg \cdot 100\ g^{-1}$ and 269 $mg \cdot 100\ g^{-1}$, respectively. In strain 3 the contents were 0.92%, 132 $mg \cdot 100\ g^{-1}$, 293 $mg \cdot 100\ g^{-1}$ and 242 $mg \cdot 100\ g^{-1}$, respectively. Strain 1 was an early-maturing variety with a thin nutshell, and had a higher nitrogen, phosphorus and potassium content than the other two strains, but strain 2 and strain 3 were late-maturing varieties and strain 3 had the thickest nutshell but the kernel was full and big.

4 Conclusions

For the three strains of hazelnuts tested, the contents of nitrogen, phosphorus, potassium and calcium decreased sharply during the young fruit rapid growth stage. During the kernel development stage, the kernel volume expanded remarkably till it was completely full in the fruit cavity and dry matter started to accumulate in the kernel. During this stage, the content of nitrogen, phosphorus and potassium in the hazel fruit increased remarkably. Most of the nitrogen was used for the synthesis of protein, and phosphorus and potassium were mainly related to the development of the hazelnut kernel and the maturity of the fruit. There was a great demand for nitrogen, phosphorus and potassium to meet the development of the kernel.

The young fruit rapid growth stage and kernel development stage were the critical periods for the absorption and accumulation of mineral elements in the fruit. Generally, there should be an application of basic fertilizer in autumn and an application of top dressing from late May to early June (compound fertilizer as a main source), thus satisfying the nutrient demand for young fruit development and new shoots growth. An application of top dressing or foliage spray is necessary from early July to mid July, because this period is of vital importance to the fruit development, flower bud differentiation and branch enrichment.

The contents of nitrogen, phosphorus and potassium in the hazelnut fruit continued to increase from kernel growth stage till nut maturity stage, in which the content of phosphorus in the hazelnut fruit decreased dramatically, and the reason for this was probably due to the great consumption in the kernel development and less absorption. Calcium played a role in balancing the physiological activities in the hazel tree. As the absorption of calcium was mainly conducted during the young fruit rapid growth stage, the accumulation of calcium during this stage was to supply the development of hazelnut fruit in the middle and late stages.

In the development course of hazel fruit, there existed a very significantly positive correlation between the three elements of nitrogen, phosphorus and potassium. For the sake of practical production, we should pay much attention to maintaining the balance between the three elements, so as to raise the yield and improve nut quality.

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