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Correlation between soil environment and yield and quality of Sharen (Amomi Fructus) under different planting patterns

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ABSTRACT

Objective To study the effects of soil environment on the growth, yield, and quality of Sharen (Amomi Fructus) under different planting patterns.

Methods Soil physical and chemical indices and enzyme activities in four periods including early flowering (March), full flowering (June), fruit ripening (September), and late fruit picking (December), were measured under three planting patterns including natural forest, greenhouse, and rubber forest in Xishuangbanna, China. The changes in soil indices during the growth periods of Sharen (Amomi Fructus) under different planting patterns were analyzed, and the differences in plant growth, yield, and quality under different planting patterns were explored. Pearson correlation analysis was used to analyze the relationship between soil indices and Sharen (Amomi Fructus) growth, yield, and quality. Principal component analysis was used to investigate the effects of soil environment under different planting patterns on Sharen (Amomi Fructus) growth, yield, and quality.

Results The soil moisture, available potassium content, and urease activity of the three planting patterns of Sharen (Amomi Fructus) increased initially and decreased afterwards throughout the year; pH and organic matter content showed little change in the whole year. Exchangeable manganese content and acid phosphatase activity gradually increased throughout the year. Hydrolyzed nitrogen content, exchangeable calcium content, available zinc content, protease activity, and sucrase activity decreased initially and increased afterwards throughout the year. Exchangeable magnesium content, available iron content, and catalase activity decreased annually. Total nitrogen content, total phosphorus content, and available phosphorus content fluctuated throughout the year. The total potassium content under natural forest and greenhouse planting decreased throughout the year, while the total potassium content under rubber forest showed an upward trend all year round. The organic matter content, total nitrogen content, total potassium content, available potassium content, available zinc content, urease activity, acid phosphatase activity, and catalase activity under greenhouse were significantly lower than those under natural and rubber forests ($P < 0.05$). Correlation analysis showed that plant growth, yield, and quality of Sharen (Amomi Fructus) were significantly correlated with soil organic matter, total nitrogen, hydrolyzed nitrogen, total phosphorus, available phosphorus, total potassium, available potassium, exchangeable manganese, exchangeable magnesium, exchangeable calcium, available zinc, urease, acid phosphatase, and invertase ($P < 0.05$). The results of the principal component analysis

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indicated that the soil environment of Sharen (Amomi Fructus) under natural forest was the best, followed by rubber forest and greenhouse. The order of its advantages and disadvantages is consistent with the growth index of Sharen (Amomi Fructus), but contrary to the yield of Sharen (Amomi Fructus), indicating that the soil environment directly affects the growth index and nutritional components of plants.

Conclusion Different planting patterns of Sharen (Amomi Fructus) have different soil nutrient content, and the change rules in the growths period are not similar, with some differences. Soil indices have impacts on plant growth, yield, and quality of Sharen (Amomi Fructus). Soil ecological environment is positively correlated with the growth characteristics of Sharen (Amomi Fructus) plants, but has no direct correlation with yield and quality.

1 Introduction

Sharen (Amomi Fructus) is one of the "Four Southern Herbal Medicines" in China, and one of the 101 varieties with homology of medicine and food announced by the National Health and Family Planning Commission of the People's Republic of China, with a history of over 1 300 years as medicine and food. It has the effects of resolving dampness, stimulating appetite, warming the spleen, relieving diarrhea, regulating Qi, calming down, etc. It can be used for diseases such as damp turbidity obstructing the center, gastric stuffiness without hunger, deficiency-cold of spleen and stomach, vomiting and diarrhea, malign obstruction in pregnancy, threatened abortion, etc. Sharen (Amomi Fructus) included in the current *Pharmacopoeia of the People's Republic of China* (*Chinese Pharmacopoeia*, 2020 edition) are the dried and mature fruits of Zingiberaceae including *Amomum villosum* Lour., *Amomum villosum* Lour. var. *xanthioi*des T. L. Wu et Senjen, or *Amomum longiligulare* T. L. Wu [1]. *Amomum villosum* Lour. var. *xanthioi*des T. L. Wu et Senjen and *Amomum longiligulare* T. L. Wu gradually fade out of the market because of their weak taste and insufficient medicinal properties. At present, Sharen (Amomi Fructus) circulating in the market is mainly *Amomum villosum* Lour. with its production area located in Yangchun, Guangdong Province. Currently, Yunnan is the production area with the largest cultivation area and yield, followed by Guangxi, Guangdong, and Fujian. By 2020, the planting area in Yunnan Province is 455 000 mu, of which Xishuangbanna is about 200 000 mu, accounting for approximately 50% of the planting area of Sharen (Amomi Fructus) in Yunnan Province.

Sharen (Amomi Fructus) is a semi-shade plant, which likes diffuse light, avoids direct sunlight for a long time, and is suitable for shade of 40% – 70%, so it is mostly planted under forests. The ecological environment of Sharen (Amomi Fructus) varies under different planting patterns, and the ecological environment has an important impact on its growth and development, and indirectly affects its yield and quality. ZHANG et al. [2] found that the differences in the ecological environment such as climate factors, soil composition, and water conditions in different planting areas, as well as farmers' different mastery of cultivation techniques, led to differences in plant type, fruit characters, and effective content of *Amomum villosum* Lour.. Soil acts as one of the important ecological factors affecting the growth of *Amomum villosum* Lour.. Soil properties and soil microorganisms have certain effects on the growth and reproduction process of *Amomum villosum* Lour.. LIN [3] held that soil texture and pH had impacts on the growth of Sharen (Amomi Fructus), which is suitable for growing in fertile and loose loam rich in humus, neutral or slightly acidic, or ash loam under forest, but not suitable for growing in sandy soil or barren soil with poor water and fertilizer retention. HUANG et al. [4] found that there was a positive correlation between the content of zinc and manganese in soil and Sharen (Amomi Fructus) fruit; the content of zinc and manganese in Sharen (Amomi Fructus) fruit were higher, the content of volatile oil was higher, and the quality of medicinal materials was better. MA et al. [5] reported that zinc and manganese could promote the germination of new bamboo shoots and improve the fruit-setting rate. LI et al. [6] found that in areas where the content of available potassium and total nitrogen in the soil was high, and the soil pH value, the content of organic matter, and phosphorus were relatively low, the occurrence degree of leaf blight was low, and the yield of Sharen (Amomi Fructus) was high. It is inferred that soil fertility affects the resistance of plants to diseases, thus affecting the occurrence degree of leaf blight. Therefore, the soil environment has a certain influence on the growth, yield, and quality of Sharen (Amomi Fructus). Xishuangbanna in Yunnan province of China is the main planting area of Sharen (Amomi Fructus), and the planting modes of Sharen (Amomi Fructus) there mainly include natural forest, rubber forest, and greenhouse. At present, there is no literature on the correlation between soil environment and yield and quality of Sharen (Amomi Fructus) in Xishuangbanna.

In this study, water content, pH value, organic matter, nitrogen, phosphorus, potassium, calcium, iron, zinc, fermentation, and biological enzymes were used as soil indices under three planting patterns, namely natural forest, rubber forest, and greenhouse in Xishuangbanna, China. Soil indices were measured in four periods: early flowering (March), full flowering (June), fruit ripening (September), and late fruit picking (December). The characteristics of change in soil indices in the Sharen (Amomi Fructus) growth periods under different planting patterns were analyzed, and the relationship between them and Sharen (Amomi Fructus) growth periods was discussed. The differences in growth, yield, and quality of Sharen (Amomi Fructus) under different planting patterns were studied. Pearson correlation analysis was used to analyze the relationship between soil indices and the growth, yield, and quality of Sharen (Amomi Fructus). Principal component analysis was adopted to study the effects of soil environment under different planting patterns on the growth, yield, and quality of Sharen (Amomi Fructus). This paper aims to improve the yield of Sharen (Amomi Fructus), choose reasonable planting mode and scientific fertilization to provide the corresponding theoretical basis, so as to fundamentally promote the purpose of increasing its yield and ensuring quality.

2 Materials and methods

2.1 Overview of the test area

The Sharen (Amomi Fructus) plots with the same germplasm resources and planting years, entering the full fruit period in Xishuangbanna Prefecture, Yunnan Province, China, were selected as the study sample plots. The general situation of three Sharen (Amomi Fructus) planting patterns (natural forest, rubber forest, and greenhouse) is shown in Table 1. Rhizosphere soils were collected in March, June, September, and December of 2022. The soil samples were dried at room temperature, levigated in a mortar, and screened with a 100 mesh sieve for physicochemical and enzyme activity analyses.

2.2 Detection indices and analysis methods

2.2.1 Physical and chemical properties of soil The soil samples collected in four periods were measured, including water content, pH, organic matter, total nitrogen (hydrolyzed nitrogen), total phosphorus (available phosphorus), total potassium (available potassium), exchangeable energy, exchangeable calcium, exchangeable magnesium, available iron, and available zinc. The soil samples were determined by referring to the Agricultural Industrial Standards of the People's Republic of China: Determination of Forest Soil Water Content (LY/T 1213-1999), Determination of pH Value in Forest Soil (LY/T 1239-1999), Determination of Organic Matter in Forest Soil and Calculation Carbon-Nitrogen Ratio (LY/T 1237-1999), Nitrogen Determination Methods of Forest Soils (LY/T 1228-2015), Phosphorus Determination Methods of Forest Soils (LY/T 1232-2015), Potassium Determination Methods of Forest Soils (LY/T 1234-2015), Determination of Exchangeable Manganese in Forest Soil (LY/T 1263-1999), Determination of Exchangeable Calcium and Magnesium in Forest Soil (LY/T 1245-1999), Determination of Available Zinc in Forest Soil (LY/T 1261-1999), and Determination of Available Iron in Forest Soil (LY/T 1262-1999).

2.2.2 Enzyme activity of soil The soil sample was determined in four collection periods. The activities of urease, acid phosphatase, catalase, protease, and sucrase were taken as indices, and were determined by referring to *Soil Enzyme and Its Research Method* by GUAN [7]. The activity of urease was determined by sodium phenol-sodium hypochlorite colorimetry, the activity of acid phosphatase by disodium phosphate colorimetry, the activity of catalase by potassium permanganate titration, the activity of invertase by molybdenum-copper colorimetry, and the activity of protease by copper salt colorimetry.

2.2.3 Determination of plant growth index, yield, and quality The number, height, and diameter of Sharen (Amomi Fructus) strong plants in each quadrant (the diameter at 40 cm perpendicular to the ground) were determined in June, and Sharen (Amomi Fructus) plants in the quadrant were collected. After cleaning, drying, and crushing, the content of total nitrogen, total phosphorus, and total potassium was measured and repeated for three times. In September, Sharen (Amomi Fructus) in each sample was collected, dried, and weighed. According to the 2020 edition of *Chinese Pharmacopoeia*, the content of volatile oil and bornyl acetate in Sharen (Amomi Fructus) was determined. Because the results of Sharen (Amomi Fructus) in the sample were insufficient to determine the volatile oil and bornyl acetate, Sharen (Amomi Fructus) fruits were diffused around the sample as the center point in the experiment. The determination was repeated three times in each planting mode.

Table 1 General situation of different Sharen (Amomi Fructus) planting patterns in Xishuangbanna

Planting pattern	Planting time	Sharen germplasm	Latitude and longitude	Altitude (m)	Soil type	Location
Natural forest	2018	Ma Guan	21°30'17" N, 101°29'30" E	919.85	Sandy loam	Mengla County garbage dump
Rubber forest	2018	Ma Guan	21°16'47" N, 101°32'19" E	894.33	Sandy loam	Longmen Village, Shang Yong Town, Mengla County
Greenhouse	2018	Ma Guan	21°17'47" N, 101°33'25" E	882.07	Sandy soil	Longmen Village, Shang Yong Town, Mengla County

2.3 Statistital analysis

The data were plotted by Origin 8.0, and the experimental data were analyzed by SPSS 22.0 for statistical analyses. The data in the chart are expressed as mean ± standard deviation (SD). One-way ANOVA was used to compare the differences in soil indices under three planting patterns and different growth periods under the same planting pattern in the same period. If significant differences were observed among soil indices (P < 0.05), they were expressed by different numbers or letters, while if there were no significant differences among soil indices, they were expressed by the same numbers or letters (P > 0.05). Person correlation analysis was used to analyze the relationship between soil indices and Sharen (Amomi Fructus) growth, yield, and quality. Principal component analysis was used to study the effects of soil environment under different planting patterns on Sharen (Amomi Fructus) growth, yield, and quality.

3 Results

3.1 Changes of physical and chemical properties in rhizosphere soil of Sharen (Amomi Fructus) under different planting patterns

3.1.1 Moisture As can be seen from Figure 1A, the water content under natural forest in the same period was significantly higher than that under other modes (P < 0.05). The water content under natural forest and rubber forest increased initially and decreased afterwards in the whole year, and the difference of water content in different periods was significant (P < 0.05). No significant difference was observed between different periods under greenhouse (P > 0.05).

3.1.2 pH values In the same period, the pH values decreased sequentially under greenhouse, rubber forest, and natural forest, and the pH under natural forest is significantly lower than that under greenhouse and rubber forest (P < 0.05; Figure 1B). The pH under three modes changed little throughout the year, without significant difference in different periods (P > 0.05).

3.1.3 Organic matter The content of organic matter decreased sequentially under rubber forest, natural forest, and greenhouse except in March (Figure 1C). The content of organic matter under greenhouse was significantly lower than that under other modes all year round (P < 0.05). The content of organic matter under three modes showed little change in the whole year, without significant differences in different periods (P > 0.05).

3.1.4 Total nitrogen and hydrolyzed nitrogen The content of total nitrogen under natural forest and rubber forest was significantly higher than that under greenhouse at the same period (P < 0.05; Figure 1D). The content of total nitrogen under three models was fluctuating, and that under greenhouse in different periods was significantly different (P < 0.05). The content of hydrolyzed nitrogen under natural forest was significantly higher than that under other modes in the same period (P < 0.05; Figure 1E). The content of hydrolyzed nitrogen under natural forest and rubber forest decreased initially and increased afterwards throughout the year, and that under greenhouse increased initially and decreased afterwards.

3.1.5 Total phosphorus and available phosphorus The content of total phosphorus under three modes was fluctuating, with significant differences in different periods under the same mode (P < 0.05; Figure 1F). The content of available phosphorus under greenhouse was significantly higher than that under other modes in the same period (P < 0.05; Figure 1G). The content of available phosphorus under greenhouse fluctuated yearly. The content of available phosphorus under natural forest decreased first and then increased, and that under rubber forest increased first and then decreased.

3.1.6 Total potassium and available potassium The content of total potassium under natural forest and greenhouse decreased all year round, and that under rubber forest showed an upward trend all year round (Figure 1H). From March to September, the content of total potassium in the same period decreased sequentially under natural forest, rubber forest, and greenhouse, with significant differences (P < 0.05). In December, the content of total potassium under rubber forest increased to the highest level, which was significantly higher than that under other modes (P < 0.05). The content of available potassium under natural forest increased first and then decreased, and that under rubber forest decreased first and then increased (Figure 1I). The content of available potassium under greenhouse has little change throughout the year. Except in December, the content of available potassium under natural forest was significantly higher than that under rubber forest, and the latter was significantly higher than that under greenhouse (P < 0.05).

3.1.7 Exchangeable manganese The exchangeable manganese under three modes gradually increased throughout the year, and significant differences were observed in different periods (P < 0.05; Figure 2A). Except in March, the content of exchangeable manganese under greenhouse was significantly higher than that under other modes (P < 0.05).

3.1.8 Exchangeable calcium and exchangeable magnesium The content of exchangeable calcium under three modes decreased initially and increased afterwards throughout the year, reaching the lowest value in September (Figure 2B). In the same period, the content of exchangeable calcium under three modes decreased sequentially under greenhouse, rubber forest, and natural forest, with significant differences (P < 0.05). The content of exchangeable magnesium under three modes decreased all year round, and that under natural forest and rubber forest was significantly different in different periods (P < 0.05; Figure 2C); while there was no significant difference under greenhouse in other periods except March (P > 0.05). In the same period, the exchangeable magnesium content of the three modes decreased sequentially under greenhouse, rubber forest, and natural forest, with significant differences (P < 0.05).

3.1.9 Available iron The content of available iron under three modes decreased significantly all year round in different periods (P < 0.05; Figure 2D). Except for September, there was no significant difference in the content of available iron among the three modes in other periods (P > 0.05).

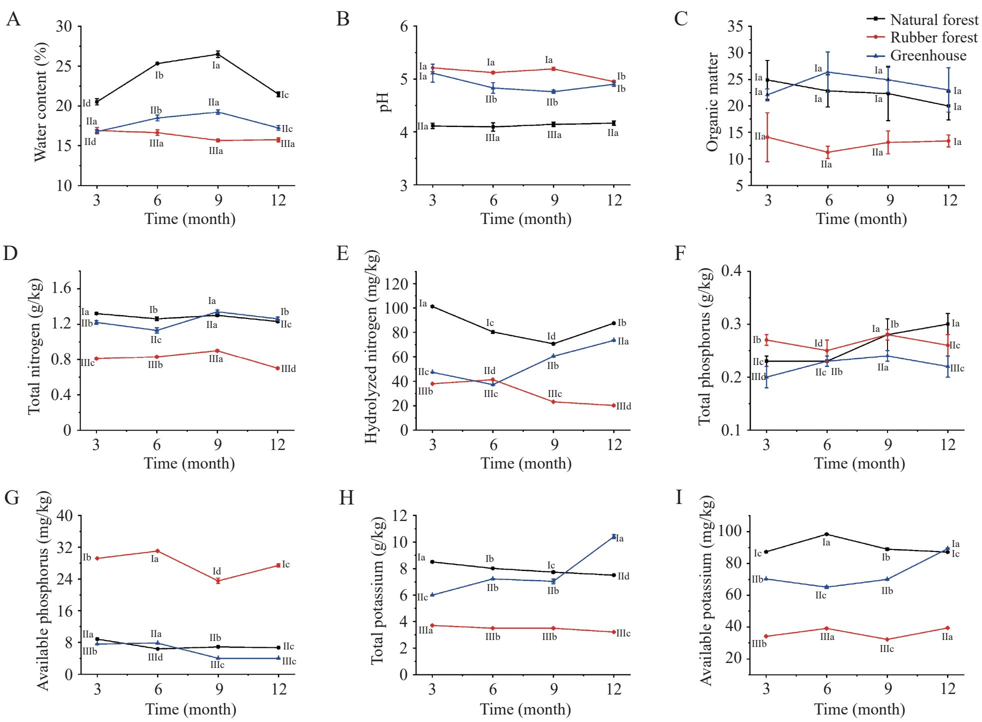

Figure 1 Changes of basic nutrients in rhizosphere soil of Sharen (Amomi Fructus) under different planting patterns

A, moisture. B, pH. C, Drganic matter. D, total nitrogen. E, hydrolyzed nitrogen. F, total phosphorus. G, available phosphorus. H, total potassium. I, available potassium. Different uppercase Roman numerals (I, II, and III) indicate significant differences among different planting patterns in the same period (P < 0.05); different lowercase letters (a, b, c, and d) indicate significant differences among different periods under the same planting pattern (P < 0.05).

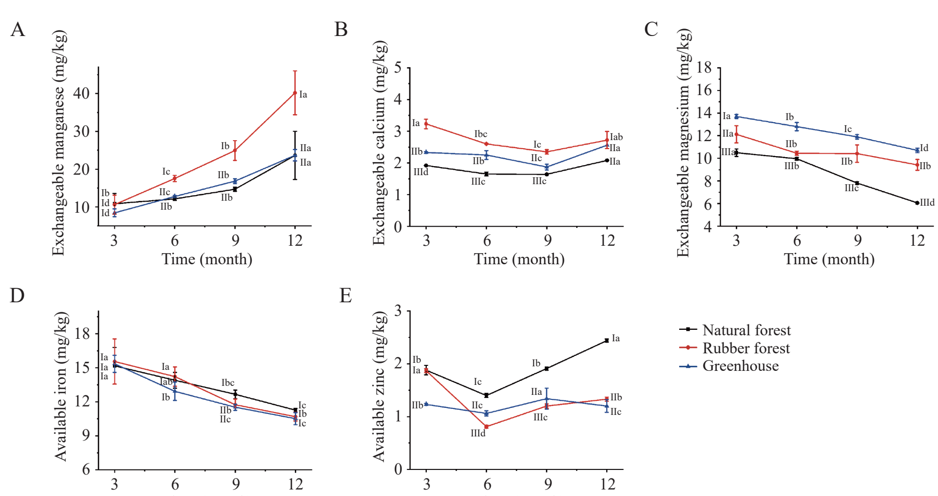

Figure 2 Changes of inorganic elements in rhizosphere soil of Sharen (Amomi Fructus) under different planting patterns

A, exchangeable manganese. B, exchangeable calcium. C, exchangeable magnesium. D, available iron. E, available zinc. Different uppercase Roman alphanumeric letters (I, II, and III) indicate significant differences among different planting patterns in the same period (P < 0.05); different lowercase letters (a, b, c, and d) indicate significant differences among different periods under the same planting pattern (P < 0.05).

3.1.10 Available zinc The content of available zinc under natural forest and greenhouse decreased first and then increased, reaching the lowest value in June (Figure 2E). The content of available zinc under rubber forest fluctuated throughout the year, with significant differences in different periods ($P < 0.05$). Meanwhile, the content of available zinc under natural forest was significantly higher than that under other modes ($P < 0.05$).

3.2 Changes of enzyme activity in rhizosphere soil of Sharen (Amomi Fructus) under different planting patterns

3.2.1 Urease The urease activity under greenhouse was significantly lower than of that under other patterns in the same period ($P < 0.05$; Figure 3A). The urease activity under different planting patterns increased first and then decreased, and reached the maximum in September. The urease activity under natural forest and rubber forest was significantly different in different periods ($P < 0.05$), and that under greenhouse was significantly different in other periods except for June and December ($P < 0.05$).

3.2.2 Acid phosphatase The activity of acid phosphatase decreased sequentially under natural forest, rubber forest, and greenhouse in the same period, with significant differences ($P < 0.05$; Figure 3B). The activity of acid phosphatase under different planting patterns showed an overall increasing trend, and that in different periods under the same planting pattern was significantly different ($P < 0.05$).

3.2.3 Catalase The catalase activity decreased sequentially under rubber forest, natural forest, and greenhouse in the same period, with significant differences ($P < 0.05$; Figure 3C). The catalase activity under different planting patterns showed a downward trend. There was no significant difference between March and June, September and December under rubber forest ($P > 0.05$). There were significant differences of catalase activity in different periods under natural forest ($P < 0.05$). No significant difference was observed between September and December under greenhouse ($P > 0.05$), but a significant difference was observed between other two periods ($P < 0.05$).

3.2.4 Protease The protease activity under rubber plantation was higher than that under other patterns in the same period ($P < 0.05$; Figure 3D). The protease activity under different planting patterns decreased first and then increased, which reached the lowest level in September. Under the same planting pattern, there were significant differences of protease activity at different periods ($P < 0.05$).

3.2.5 Sucrase There were significant differences of the sucrase activity under different planting patterns in the same period ($P < 0.05$; Figure 3E). The sucrase activity in March decreased sequentially under natural forest, rubber forest, and greenhouse; in June decreased sequentially under rubber forest, natural forest, and greenhouse; in September and December decreased sequentially under greenhouse, rubber forest, and natural forest. The sucrase activity under natural forest decreased first and then increased, which reached the lowest level in December, with significant differences among different periods ($P < 0.05$). The sucrase activity under rubber forest and greenhouse increased throughout the year, and there were significant differences in different periods ($P < 0.05$).

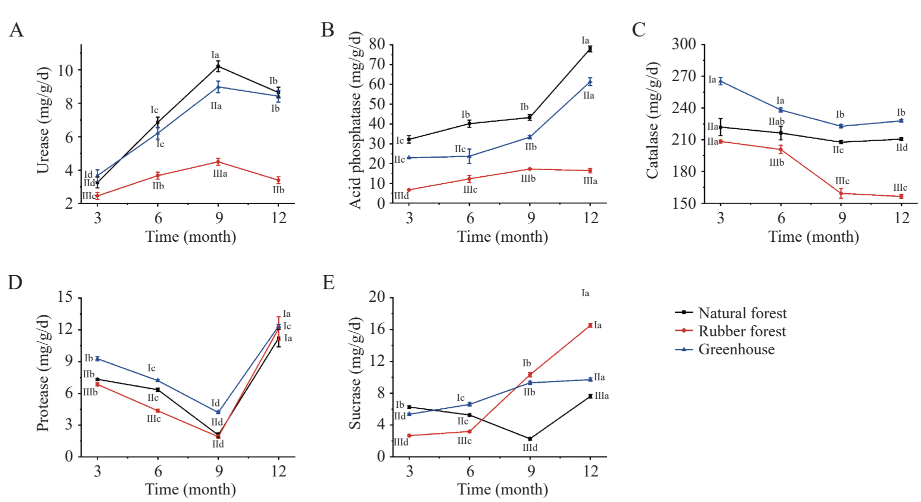

Figure 3 Changes of enzyme activity in rhizosphere soil of Sharen (Amomi Fructus) under different planting patterns

A, urease. B, acid phosphatase. C, catalase. D, protease. E, sucrase. Different uppercase Roman alphanumeric letters (I, II, and III) indicate significant differences among different planting patterns in the same period ($P < 0.05$); different lowercase letters (a, b, c, and d) indicate significant differences among different periods under the same planting pattern ($P < 0.05$).

3.3 Effects of different planting patterns on growth index, yield, and quality of Sharen (Amomi Fructus)

The number of strong plants per square meter under different planting modes is 25.8 - 30.8, and the number of strong plants decreased sequentially under greenhouse, rubber forest, and natural forest, without significant difference among different planting modes ($P > 0.05$; Table 2). The height of Sharen (Amomi Fructus) under different planting patterns ranged from 185.08 cm to 206.52 cm, and decreased sequentially under natural forest, rubber forest, and greenhouse. The height of strong plants under natural forest was significantly higher than that under greenhouse and rubber forest ($P < 0.05$), but no significant difference was observed between greenhouse and rubber forest ($P > 0.05$). The diameter of the strong plant of Sharen (Amomi Fructus) under different planting patterns ranged from 13.27 mm to 13.99 mm, and decreased sequentially under rubber forest, greenhouse, and natural forest, without significant difference among different planting patterns ($P > 0.05$). The total nitrogen content of Sharen (Amomi Fructus) plants under different planting patterns ranged from 9.27 g/kg to 15.45 g/kg, decreasing sequentially under natural forest, rubber forest, and greenhouse, and the difference under different planting patterns was significant ($P < 0.05$). The total phosphorus content of Sharen (Amomi Fructus) under different planting patterns ranged from 8.12 g/kg to 12.92 g/kg, decreasing sequentially under natural forest, rubber forest, and greenhouse, and the difference under different planting patterns was significant ($P < 0.05$). The total potassium content of strong plants of Sharen (Amomi Fructus) under different planting patterns ranged from 7.29 g/kg to 16.25 g/kg, decreasing sequentially under natural forest, rubber forest, and greenhouse, and the difference under different planting patterns was significant ($P < 0.05$). The number of Sharen (Amomi Fructus) fruit per square meter under different planting patterns ranged from 2.5 to 15.3, and decreased sequentially under greenhouse, rubber forest, and natural forest. The yield of dried Sharen (Amomi Fructus) under different planting patterns ranged from 1.5 g/m^2 to 11.6 g/m^2, and decreased sequentially under greenhouse, rubber forest, and natural forest. The content of volatile oil and bornyl acetate of Sharen (Amomi Fructus) under three planting patterns all reached the standard of *Chinese Pharmacopoeia* (2020 edition), without significant difference ($P > 0.05$).

3.4 Correlation between soil indices and growth status, yield, and quality of Sharen (Amomi Fructus) plants

Pearson correlation analysis between soil indices and the growth status, yield, and quality of Sharen (Amomi Fructus) plants was carried out using SPSS 22.0, and the results are shown in Table 3. The number of strong plants is significantly correlated with total nitrogen, total potassium, exchangeable manganese, and urease. Plant height is significantly correlated with available zinc; diameter is significantly correlated with total phosphorus and invertase; total nitrogen in plants is significantly correlated with hydrolyzed nitrogen and urease in soil. In addition, total phosphorus in plants is significantly correlated with total phosphorus, available phosphorus, exchangeable magnesium, and acid phosphatase in soil; total potassium in plants is significantly correlated with available potassium and exchangeable calcium; dried fruit yield is significantly correlated with total nitrogen, available phosphorus, exchangeable manganese, and urease; volatile oil is significantly correlated with organic matter, total nitrogen, available phosphorus, total potassium, exchangeable manganese, and urease; and bornyl acetate is significantly correlated with total phosphorus. It can be seen that organic matter, total nitrogen, hydrolyzed nitrogen, total phosphorus, available phosphorus, total potassium, available potassium, exchangeable manganese, exchangeable magnesium, exchangeable calcium, available zinc, urease, acid phosphatase,

Table 2 Analysis of plant growth, yield, and quality of Sharen (Amomi Fructus) under different planting patterns

Planting pattern	Number of strong plants (plants)	Strong plant height (cm)	Strong plant diameter (mm)	Total nitrogen (g/kg)	Total phosphorus (g/kg)
Natural forest	25.80 ± 9.26^a	206.52 ± 23.59^a	13.27 ± 2.38^a	15.45 ± 1.12^a	12.92 ± 0.48^a
Rubber forest	26.40 ± 3.28^a	190.72 ± 47.09^b	13.99 ± 1.57^a	13.34 ± 0.94^b	9.72 ± 0.22^b
Greenhouse	30.80 ± 7.95^a	185.08 ± 35.19^b	13.56 ± 1.37^a	9.27 ± 0.36^c	8.12 ± 0.08^c

Planting pattern	Total potassium (g/kg)	Number of fruits (pc/m^2)	Dried fruit yield (g/m^2)	Volatile oil (%)	Borneol acetate (%)
Natural forest	16.25 ± 1.20^a	2.50 ± 1.20^b	1.50 ± 0.30^b	3.14 ± 0.35^a	$0.92 \pm .51^a$
Rubber forest	13.38 ± 1.05^b	3.70 ± 1.60^b	2.10 ± 0.20^b	3.14 ± 0.23^a	0.91 ± 0.05^a
Greenhouse	7.29 ± 0.20^c	15.30 ± 2.30^b	11.60 ± 0.90^a	3.16 ± 0.13^a	0.92 ± 0.03^a

Different small letters in the same column indicate significant differences under different planting patterns ($P < 0.05$), while the same letters indicate no significant difference under different planting patterns ($P > 0.05$).

Table 3 Correlation coefficients between soil indices and growth status, yield, and quality of Sharen (Amomi Fructus) plants

Factor	Number of strong plants	Plant height	Diameter	Total nitrogen	Total phosphorus	Total potassium	Dried fruit yield	Volatile oil	Bornyl acetate
Moisture	−0.825	−0.339	0.084	0.857	0.784	0.924	−0.791	−0.758	0.186
pH	0.749	0.452	−0.206	−0.787	−0.854	−0.870	0.710	0.672	−0.305
Organic matter	−0.971	0.476	−0.688	0.955	0.059	0.900	−0.983	−0.991*	−0.609
Total nitrogen	−0.999**	0.284	−0.523	0.912	0.264	0.971	−1.000*	−0.997*	−0.432
Hydrolyzed nitrogen	−0.886	−0.224	−0.035	0.996*	0.704	0.963	−0.858	−0.830	0.068
Total phosphorus	0.402	−0.987	0.995*	−0.347	0.993*	−0.203	0.453	0.500	1.000**
Available phosphorus	0.987	−0.407	0.630	−0.975	0.991*	−0.931	0.994*	0.999**	0.546
Total potassium	−0.998**	0.306	−0.542	0.756	0.242	0.965	−1.000**	−0.999**	−0.453
Available potassium	−0.981	0.058	−0.314	−0.136	0.477	1.000**	−0.968	−0.953	−0.215
Exchangeable manganese	0.995*	−0.347	0.578	−0.987	−0.200	−0.953	0.999**	1.000**	0.491
Exchangeable calcium	0.926	0.132	0.128	−0.946	−0.635	−0.994*	0.903	0.879	0.026
Exchangeable magnesium	0.162	0.914	−0.778	−0.220	−0.991*	−0.363	0.106	0.053	−0.838
Available iron	0.118	−0.718	0.922	−0.059	0.914	0.090	0.175	0.227	0.957
Available zinc	−0.493	−0.991*	0.513	0.543	0.977	0.663	−0.442	−0.394	0.599
Urease	−1.000**	0.259	−0.500	0.998**	0.289	0.977	−0.999**	−0.995*	−0.409
Acid phosphatase	−0.965	−0.011	−0.248	0.979	0.998**	0.537	−0.948	−0.930	−0.147
Catalase	−0.854	0.719	−0.874	0.822	−0.245	0.727	−0.882	−0.906	−0.820
Protease	−0.585	0.932	−0.271	0.536	−0.602	0.404	−0.630	−0.671	−0.978
Invertase	0.703	0.511	−0.994*	−0.744	−0.887	−0.835	0.661	0.620	−0.369

$^{*}P < 0.05$, $^{**}P < 0.01$.

and invertase in soil have particular effects on plant growth index, yield, and quality of Sharen (Amomi Fructus), while water, pH, available iron, catalase, and protease have little effect on these indices.

3.5 Evaluation of soil environment under different planting patterns and its relationship with plant growth, yield, and quality

The results of correlation analysis showed that organic matter, total nitrogen, hydrolyzed nitrogen, total phosphorus, available phosphorus, total potassium, available potassium, exchangeable manganese, exchangeable magnesium, exchangeable calcium, available zinc, urease, acid phosphatase, and invertase in the soil had significant correlation with plant growth characteristics, yield and quality of Sharen (Amomi Fructus). Because soil factors often restrict, influence, and interact with each other, in order to explore the leading factors affecting the growth, yield, and quality of Sharen (Amomi Fructus), principal component analysis was carried out on the above indicators, and the contribution rate of principal component variance was obtained (Table 4). According to the principle of eigenvalue over 1, three principal components were extracted, and their eigenvalues are 7.387, 3.016, and 1.692, respectively, with their cumulative contribution rate reaching 86.37%, which shows that the above three principal components can represent the changing trend of the data.

Table 4 Eigenvalue and variance contribution rate of principal component factors in soil environment of Sharen (Amomi Fructus)

Principal component	Eigenvalue	Variance contribution rate (%)	Cumulative variance contribution rate (%)
1	7.387	52.761	52.761
2	3.016	21.541	74.302
3	1.692	12.084	86.386

1, 2, and 3 represent the extracted principal component factors.

From Table 5, it can be seen that nine indices of organic matter, total nitrogen, hydrolyzed nitrogen, available phosphorus, total potassium, available potassium, exchangeable calcium, urease, and acid phosphatase have a higher matrix in principal component 1. Total phosphorus, exchangeable manganese, exchangeable magnesium, and available zinc have higher matrix in principal component 2. Exchangeable manganese and invertase have a higher matrix in principal component 3. In summary, organic matter, total nitrogen, hydrolyzed nitrogen, total phosphorus, available phosphorus, total potassium, available potassium, exchangeable manganese, exchangeable magnesium, exchangeable calcium,

Table 5 Eigenvectors and load matrices of three principal components of Sharen (Amomi Fructus) soil environment

Indicator		Organic matter (%)	Total nitrogen (g/kg)	Hydrolyzed nitrogen (mg/kg)	Total phosphorus (g/kg)	Available phosphorus (mg/kg)	Total potassium (g/kg)	Available potassium (mg/kg)
Principal component 1	Eigenvector	0.116	0.130	0.118	– 0.027	– 0.128	0.126	0.131
	Load	0.859*	0.964*	0.868*	– 0.198	– 0.942*	0.931*	0.969*
Principal component 2	Eigenvector	– 0.120	– 0.062	0.035	0.285	0.051	– 0.035	– 0.002
	Load	– 0.362	– 0.186	0.105	0.858*	0.152	– 0.106	– 0.005
Principal component 3	Eigenvector	0.100	0.007	– 0.137	– 0.207	– 0.128	0.094	0.022
	Load	0.169	0.012	– 0.231	– 0.351	– 0.217	0.160	0.036

Indicator		Exchangeable manganese (mg/kg)	Exchangeable calcium (mg/kg)	Exchangeable magnesium (mg/kg)	Available zinc (mg/kg)	Urease ($mg{\cdot}g^{-1}{\cdot}d^{-1}$)	Acid phosphatase ($mg{\cdot}g^{-1}{\cdot}d^{-1}$)	Invertase ($mg{\cdot}g^{-1}{\cdot}d^{-1}$)
Principal component 1	Eigenvector	– 0.051	– 0.106	– 0.037	0.057	0.100	0.107	– 0.033
	Load	– 0.377	– 0.781*	– 0.275	0.419	0.738*	0.792*	– 0.243
Principal component 2	Eigenvector	0.022	– 0.015	– 0.303	0.192	0.110	0.158	0.110
	Load	0.670*	– 0.045	– 0.915*	0.578*	0.330	0.476	0.333
Principal component 3	Eigenvector	0.371	– 0.017	0.073	– 0.283	0.105	0.083	0.502
	Load	0.627*	– 0.029	0.124	– 0.479	0.177	0.140	0.850*

* represents |load | > 0.5.

available zinc, urease, acid phosphatase, and invertase are all characteristic elements in soil of Sharen (Amomi Fructus).

To further analyze the influence of the soil environment on the growth, yield, and quality of Sharen (Amomi Fructus) under different planting patterns, the score coefficient matrix of relevant factors was obtained according to the ratio of the arithmetic square root of each soil factor load to each factor characteristic vector (Table 6). Therefore, the formula of principal component 1 is: $F_1 = 0.316X_1 - 0.139X_2 - 0.287X_3 - 0.101X_4 + 0.154X_5 + 0.355X_6 + 0.319X_7 - 0.073X_8 - 0.347X_9 + 0.343X_{10} + 0.357X_{11} + 0.272X_{12} + 0.291X_{13} - 0.089X_{14}$; the formula of principal component 2 is: $F_2 = -0.208X_1 + 0.386X_2 - 0.026X_3 - 0.527X_4 + 0.333X_5 - 0.107X_6 + 0.060X_7 + 0.494X_8 + 0.088X_9 - 0.061X_{10} - 0.003X_{11} + 0.190X_{12} + 0.274X_{13} + 0.192X_{14}$; the formula of principal component 3 is: $F_3 = 0.130X_1 + 0.482X_2 - 0.022X_3 + 0.095X_4 - 0.368X_5 + 0.009X_6 - 0.178X_7 - 0.270X_8 - 0.167X_9 + 0.123X_{10} + 0.028X_{11} + 0.136X_{12} + 0.108X_{13} + 0.653X_{14}$. In the formula, $X_1 - X_{14}$ represent the standardized values of soil organic matter, total nitrogen, hydrolyzed nitrogen, total phosphorus, available phosphorus, total potassium, available potassium, exchangeable manganese, exchangeable calcium, exchangeable magnesium, available zinc, urease, acid phosphatase, and invertase, respectively.

Table 6 Coefficient matrix of principal component analysis of Sharen (Amomi Fructus) soil environment

Indicator	Organic matter (%)	Total nitrogen (g/kg)	Hydrolyzed nitrogen (mg/kg)	Total phosphorus (g/kg)	Available phosphorus (mg/kg)	Total potassium (g/kg)	Available potassium (mg/kg)
Principal component 1	0.316	– 0.139	– 0.287	– 0.101	0.154	0.355	0.319
Principal component 2	– 0.208	0.386	– 0.026	– 0.527	0.333	– 0.107	0.060
Principal component 3	0.130	0.482	– 0.022	0.095	– 0.368	0.009	– 0.178

Indicator	Exchangeable manganese (mg/kg)	Exchangeable calcium (mg/kg)	Exchangeable magnesium (mg/kg)	Available zinc (mg/kg)	Urease ($mg{\cdot}g^{-1}{\cdot}d^{-1}$)	Acid phosphatase ($mg{\cdot}g^{-1}{\cdot}d^{-1}$)	Invertase ($mg{\cdot}g^{-1}{\cdot}d^{-1}$)
Principal component 1	– 0.073	– 0.347	0.343	0.357	0.272	0.291	– 0.089
Principal component 2	0.494	0.088	– 0.061	– 0.003	0.190	0.274	0.192
Principal component 3	– 0.270	– 0.167	0.123	0.028	0.136	0.108	0.653

The evaluation model of soil environmental quality was established with three principal components representing the information expressed by the original 14 indices, and the scores of three principal components F_1, F_2, and F_3 were calculated, respectively. According to the contribution rate of principal components, the comprehensive principal component value $F = (52.76\ F_1 + 21.54\ F_1 + 12.08\ F_3)/86.38$ was obtained. The larger the comprehensive score, the better the rhizosphere soil quality. According to the formula of F, the quality evaluation of the rhizosphere soil environment under different planting modes was carried out, and the results are shown in Table 7. The comprehensive scores decereased sequentially under natural forest, rubber forest, and greenhouse. The comprehensive evaluation order of the Sharen (Amomi Fructus) rhizosphere soil ecological environment is consistent with the order of plant height, diameter, total nitrogen content, total phosphorus content, and total potassium content, which indicates that principal component analysis has certain guiding importance in the comprehensive evaluation of Sharen (Amomi Fructus) rhizosphere soil ecological environment. Compared with different Sharen (Amomi Fructus) fruit yields, the comprehensive evaluation order of Sharen (Amomi Fructus) rhizosphere soil ecological environment is inconsistent with the yield order of Sharen (Amomi Fructus) fruit, and the comprehensive evaluation of greenhouse ecological environment remains the lowest, but its yield is the highest.

Table 7 Comprehensive scores and ranking of principal component factors in soil environment of Sharen (Amomi Fructus)

Planting pattern	F_1	F_2	F_3	F	Sort
Natural forest	2.47	0.89	– 0.70	1.63	1
Rubber forest	1.03	– 1.39	0.89	0.40	2
Greenhouse	– 3.50	0.49	– 0.19	– 2.04	3

4 Discussion

4.1 Analysis of soil nutrients and enzyme activities of Sharen (Amomi Fructus) under different planting patterns

Soil nutrient refers to the ability of soil to supply effective nutrients and water to plants in the whole process of plant growth and development, and to coordinate soil air and soil temperature in the process of plant growth and development, which is a comprehensive reflection of soil physical, chemical, and biological properties [8, 9]. This experiment measured the soil nutrient changes of the growth periods, under different planting patterns of Sharen (Amomi Fructus) in Xishuangbanna, China. The results showed that the soil nutrient content under different planting patterns was different, and the change pattern in the growth periods demonstrated certain differences. The moisture under natural forest and rubber forest showed certain seasonality, and the moisture under greenhouse had almost no change. The pH and organic matter under three modes changed little throughout the year, and the organic matter under greenhouse was significantly lower than that under other modes. The change trend in total nitrogen, available nitrogen, total phosphorus, available phosphorus, total potassium and available potassium under three modes has no obvious difference with the growth periods, but it can be seen that the nutrient contents under greenhouse are significantly different from those under other modes, which may be due to the sandy soil under greenhouse that is easy to lose nutrients, resulting in low content, and the natural forest is mostly loam. The content of exchangeable manganese, exchangeable calcium, exchangeable magnesium, available iron, and available zinc under three modes has the same change trend with the growth periods. Exchangeable manganese content increased throughout the year; exchangeable magnesium content and available iron content decreased throughout the year; exchangeable calcium content decreased first and then increased throughout the year, reaching the lowest value in September; and available zinc content under three modes reached the lowest value in June. The content of exchangeable under manganese, exchangeable calcium, and exchangeable magnesium under greenhouse was higher than that under natural forest and rubber forest. There was no significant difference in available iron content among the three modes, but a significant difference was observed in available zinc content among different modes. Acid phosphatase and sucrase activities increased, catalase activity decreased, urease activity was the highest in September, and protease activity was the lowest in September. The experimental results were consistent with the changes in enzyme activity in Sharen (Amomi Fructus) rhizosphere soil in Jinping, Yunnan. Among the three modes, the enzyme activity under greenhouse is generally low, which may be due to the fact that there are fewer litters under greenhouse, and the soil moisture and nutrients are lower compared with natural forest and rubber forest, while the soil enzyme activity is affected by surface litter, underground plant roots, the number of soil microorganisms, and soil nutrients [10, 11].

4.2 Correlation between soil nutrients and growth, yield, and quality of Sharen (Amomi Fructus) under different planting patterns

Nutrients in soil not only provide the necessary material basis for the growth and development of plants, but also the interaction between different nutrients will have a certain impact on the yield and quality of plants. By analyzing the relationship between soil physical and chemical properties, soil enzyme activity and plant growth, yield, and quality of Sharen (Amomi Fructus), it was found that organic matter, total nitrogen, hydrolyzed nitrogen, total phosphorus, available phosphorus, total potassium, available potassium, exchangeable manganese, exchangeable magnesium, exchangeable calcium, available zinc, urease, acid phosphatase, and invertase in the soil had significant correlation with plant growth, yield, and quality of Sharen (Amomi Fructus), which indicated that these indices had impacts on growth, yield and quality of Sharen (Amomi Fructus), while water, pH, available iron, catalase, and protease had little impact on them. No significant correlation was observed between the water content and the growth, yield, and quality of Sharen (Amomi Fructus), which may be that the water content of air-dried soil samples measured in this study can not effectively offer feedback on the soil water content of Sharen (Amomi Fructus) growing environment. The pH of the soils under the three models ranged from 4.13 to 5.12, and all of the soils belonged to acidic or weakly acidic soils, among which weakly acidic soils were beneficial to increasing the yield of Sharen (Amomi Fructus) [3]. In this study, there is no correlation between the available iron content and the growth, yield, and quality of Sharen (Amomi Fructus), which may be that there is little difference in the available iron content under three modes. In fact, iron participates in leaf green synthesis and cell respiration [12]. Nitrogen, phosphorus, potassium, calcium, magnesium, and manganese in soil are the nutrient elements needed to ensure the growth of Sharen (Amomi Fructus) [12]. The activities of soil enzyme invertase, urease, and acid phosphatase affected the transformation of soil phosphorus, nitrogen, and organic matter [13]. LI [14] studied the growth and development indices of Sharen (Amomi Fructus) seedlings by different elements, and found that nitrogen was related to the formation of rhizomes of original plants and erect stems of new plants. Phosphorus is related to the formation of new plants, leaf formation, and induction of lower stems of new plants. Potassium has an effect on the induction of new buds and the elongation of rhizomes of original plants. Calcium is related to the induction of new leaves and buds of original plants. Zinc is related to the increase of nodes, leaves, and chlorophyll in original plants. The results of the fertilization test showed that blind fertilization of nitrogen fertilizer (urea) in production would lead to the overgrowth of plants and reduction of flowering and fruiting, so nitrogen, phosphorus, and potassium should be applied together [15]. Potassium fertilization is higher than nitrogen fertilization, and nitrogen fertilization is higher than phosphorus fertilization, that is, potassium > nitrogen > phosphorus [16]. Single or mixed fertilization of trace elements zinc, manganese, boron, and molybdenum can promote the growth and development of Sharen (Amomi Fructus) plants, delay the senescence of seedlings, increase production, and improve the quality of medicinal materials [5].

4.3 Soil environmental assessment under different planting patterns

According to the results of the principal component analysis, natural forest is the best soil environment within different planting patterns, followed by rubber forest, and greenhouse remains the worst. The better the soil environment, the better the growth index and nutrient composition of its plants, which is consistent with the research results in Jinping area, that is, the soil environment directly affects the growth characteristics of Sharen (Amomi Fructus) plants [17]. However, there is no direct correlation between soil environment and fruit yield and quality of Sharen (Amomi Fructus). The soil environment in the greenhouse is the worst but its fruit yield is the highest, while the soil environment in the natural forest is the best but its fruit yield is the lowest. This may be the result of the inconsistency of shade degrees and manual management conditions in different modes. Shade degree is one of the key factors affecting Sharen (Amomi Fructus) yield. The shade degree of three modes from high to low is natural forest, rubber forest, and greenhouse. If the shade degree is too large, the plants will grow excessively and become taller (the average strong plant height of natural forest, rubber forest, and greenhouse are 206.52, 190.72, and 185.08 cm, respectively). On one hand, the plants are easy to lodge and are not conducive to flowering and fruiting; on the other hand, it will inhibit the growth and development of new seedlings [18]. Moreover, due to poor air circulation, the humidity is too high. If the flowering period encounters the rainy season, the soil water content and the humidity will be high, which would easily cause flower burn-out and fail to guarantee the normal pollination of insects, resulting in low Sharen (Amomi Fructus) yield. YUAN et al. [19] reported that the suitable shade of Sharen (Amomi Fructus) was 50% - 60%. In this interval, the plants have the physiological and morphological characteristics of mesophytes, the population structure is reasonable, and the yield is high. In contrast, with the decrease or increase of shade degree, the plants developed towards the xerophyte or wet plant type, the population structure was poor, and the yield was low. In addition, water has a great effect on Sharen (Amomi Fructus) at the flowering and fruiting stage, and seriously affects flower bud differentiation, flowering, and pollination of Sharen (Amomi Fructus). Study has shown that soil water content of 22% - 25% and air relative humidity of 80% - 90% can ensure normal pollination of insects [20]. If the humidity is too low, the flowers are easy to dehydrate and wilt, or blossom poorly, which affects pollinating insects to visit flowers and pollinate. Meanwhile, if the humidity is too high, it would easily cause burnt flowers. Compared with other modes, the standardized management of greenhouse planting can better control shade degree and water conditions, so it has a higher yield.

5 Conclusion

The correlation between soil ecological environment and Sharen (Amomi Fructus) yield and quality under different planting patterns in Xishuangbanna, China, was studied in this research. It was found that the soil nutrient contents were different under different Sharen (Amomi Fructus) planting patterns, and the changes in the growth periods were not similar. Correlation analysis showed that organic matter, total nitrogen, hydrolyzed nitrogen, total phosphorus, available phosphorus, total potassium, available potassium, exchangeable manganese, exchangeable magnesium, exchangeable calcium, available zinc, urease, acid phosphatase, and invertase in soil all affected the plant growth, yield, and quality of Sharen (Amomi Fructus); while water, pH, available iron, catalase, and protease had little effect on these indices. The results of the principal component analysis showed that the soil environment of Sharen (Amomi Fructus) decreased sequentially under natural forest, rubber forest, and greenhouse. Soil ecological environment was positively correlated with the growth characteristics of Sharen (Amomi Fructus) plants, but had no direct correlation with yield and quality. The ecological environment of Sharen (Amomi Fructus) is affected by many factors, such as human factors (cultivation measures and management factors of farmers), biological factors (plant density, shade trees, and insect resources), climate factors, topography factors, and soil factors. In this study, we only studied the soil factors under different planting patterns but found no direct correlation between the ecological environment of Sharen (Amomi Fructus) and its yield and quality. In the future, we should include more factors such as light, water, ventilation, fertilization, ecology, climate, topography, and man-made, for further studies.

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Competing interests

The authors declare no conflict of interest.

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不同砂仁种植模式土壤环境与砂仁产量质量的相关性研究

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【**摘要**】**目的** 研究不同砂仁种植模式土壤环境对砂仁生长、产量及质量的影响。**方法** 以中国西双版纳自然林、大棚和橡胶林三种种植模式为研究对象,测定开花前期(3 月)、盛花期(6 月)、果实成熟期(9 月)和采果后期(12 月)四个时期的土壤理化指标和酶活性,分析不同种植模式下土壤指标在砂仁生长期的变化特征,探究不同种植模式下砂仁植株长势、产量与质量的区别。应用 Pearson 相关性分析土壤指标与砂仁生长、产量及质量的关系,运用主成分分析法研究不同种植模式土壤环境对砂仁生长、产量及质量的影响。**结果** 三种砂仁种植模式的土壤水分、有效钾含量和脲酶活性全年中先增大后减小;pH 和有机质含量在全年中变化不大;交换性锰含量和酸性磷酸酶活性全年逐渐增大;水解氮含量、交换性钙含量、有效锌含量、蛋白酶活性和蔗糖酶活性全年先降低后升高;交换性镁含量、有效铁含量和过氧化氢酶活性全年均降低;全氮含量、全磷含量和有效磷含量全年呈波动变化;自然林下和大棚下的全钾含量全年均降低,橡胶林下的全钾含量全年呈上升趋势。大棚的有机质含量、全氮含量、全钾含量、有效钾含量、有效锌含量、脲酶活性、酸性磷酸酶活性和过氧化氢酶活性显著低于自然林下和橡胶林下($P < 0.05$)。相关性分析结果砂仁的植株生长、产量和质量与土壤中的有机质、全氮、水解氮、全磷、有效磷、全钾、有效钾、交换性锰、交换性镁、交换性钙、有效锌、脲酶、酸性磷酸酶和转化酶显著相关($P < 0.05$)。主成分分析结果显示砂仁土壤环境: 自然林下 > 橡胶林下 > 大棚;其优劣顺序与砂仁植株的生长指标一致,但与砂仁产量相反,说明土壤环境直接影响植株的生长指标及植株的营养成分。**结论** 不同砂仁种植模式的土壤养分含量高低不同,生长期的变化规律亦不相似,具有一定的差异性。土壤指标对砂仁的植株生长、产量和质量均有影响。土壤生态环境与砂仁植株生长特征正相关,而与产量、质量无直接的相关性。

【**关键词**】砂仁; 种植模式; 土壤环境; 产量; 质量