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Effects of Uniconazole on Leaves Photosynthesis, Root Distribution and Yield of Mung Bean (*Vigna radiata*)

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Abstract

Uniconazole was a plant growth retardant with effect of regulating plant growth and development, however, there were very few studies on its application to mung bean. In this study, the leaves of mung bean were sprayed with uniconazole solution (30 mg·L^{-1}) at V3 stage. Photosynthetic indicators, root distribution were measured at R5 and R6, and yield and components were measured at maturity. Uniconazole increased Gs (stomatal conductance) and Tr (transpiration rate) at R5 and R6, Pn (net photosynthesis rate) at R6, and SPAD value at R5. The SPAD value at R5 had the greatest correlation with yield with a correlation coefficient of 0.684. According to distribution pattern of decreasing root length density from top to bottom, large amounts of water absorbed by the roots was more likely to come from the upper soil layer, especially 0–20 cm soil layer. As the depth of soil layer increased, the proportion of root dry weight in different soil layers were 69, 14, 9, 5 and 3%, respectively. Uniconazole effectively reduced root proportion in 0–20 cm soil layer and increased root proportion in 20–60 cm soil layer. Root dry weight density in 20–40 cm soil layer and yield were significantly positively correlated (r = 0.938* at R5, r = 0.891* at R6). In addition, uniconazole increased hundred grain weight and yield, reduced pods number per plant and seeds number per pod. Based on the results, this study can provide guidance for mung bean production and high-yield breeding in the future.

Keywords Mung bean · Photosynthesis · Root length · Root dry weight · Yield

Introduction

Mung bean is one of the most ancient and extensively grown legumes with the characteristics of short-term growth, strong nitrogen fixation ability and barren tolerance (Muthu et al. 2018). The root of mung bean is tap root system, which contain nodule having the N_2 fixing bacteria *Rhizobium spp*. (Khan et al. 2016). Agricultural researcher achieved the goal of high-yielding breeding by studying the relationship between root and yield. Ehdaie et al. (2012) reported that yield of bread wheat showed positive correlation with shallow and deep root dry weight under terminal drought. The study of Kanbar et al. (2009) revealed that root dry weight had the largest effect on grain yield of rice under well-watered condition. Kashiwagi et al. (2006) reported that root length density at 35 days after sowing showed a significant positive correlation with yield of chickpea in field trials. Izumi et al. (2004) showed that root length per unit area exhibited significantly positive correlation with yield in wheat but not in soybean. Karadavut and Sozen (2017) found a significant positive correlation between root weight and yield in chickpea, with a correlation coefficient of r = 0.671**. Mahdi (2013) found that there was a significant positive correlation between grain yield and root dry weight in mung bean.

Photosynthesis refers to the process in which plants absorb light energy and use carbon dioxide and water to synthesize organic matter while releasing oxygen (Pfannschmidt et al. 2010). Plants convert light energy into chemical energy while assimilating inorganic carbides and store it in the formed organic compounds (Losada et al. 1990). The light energy assimilated by photosynthesis is about 10 times more than the energy required by human

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beings every year. The chemical energy stored in organic matter is not only for plant itself and all heterotrophic organisms, but also the energy source for human nutrition and activities (Lucia et al. 2014). So it can be said that photosynthesis provides today's main energy source. Photosynthesis is closely related to agricultural production (Jens et al. 1996). Exploring the correlation between photosynthetic indicators and yield is of great significance for improving crop yield (Pepó and Novák 2016). Wang et al. (2016) found that net photosynthetic rate, stomatal conductance, transpiration rate and SPAD value of leaves were significantly positively correlated with yield in Tartary buckwheat, respectively. The research results of Bort et al. (1998) showed that the grain yield of in field grown barley was positively correlated with SPAD value. Liu et al. (2012) found that net photosynthesis rate, transpiration rate, stomatal conductance, intercellular carbon dioxide concentration and SPAD value of leaves were positively correlated with yield in soybean.

Uniconazole is a highly effective plant growth retardant, which has the effects of dwarfing crop plants, promoting root growth, preventing lodging, and improving crop resistance (Oshio et al. 1990; Fukuta et al. 2001). Uniconazole also has a bactericidal effect, and its biological activity is higher than that of paclobutrazol (Kohne and Sylvie 1989). The mechanism of uniconazole's regulation on plants is that it can affect the activity of Ent-kaurene oxidase and inhibit the synthesis of GA precursors, thereby reducing the production of endogenous GA, while inhibiting the synthesis of endogenous IAA (Hisamatsu et al. 2004; Todoroki et al. 2009). After being absorbed by the surface of plant body, uniconazole would be transported to the top through the xylem, then inhibiting the synthesis of GA, resulting in the limitation of plant cell elongation and ultimately affecting plant morphology. In recent years, the experimental studies on the application of uniconazole in crops have increased. However, due to its activity is easily affected by the environment, the actual application of uniconazole in mung bean was still less.

Materials and Methods

Experimental Site

The experiment was carried out at outdoor test site in National Coarse Cereals Engineering Research Center, Daqing, China on June 5, 2016. The annual precipitation at the experimental site was 508.7 mm, the average annual temperature was 5.60 °C, the effective accumulated temperature was 2900–3000 °C, and the sunshine duration was 1158 h (Collected from Daqing Weather Station).

Experimental Devices

The experimental device was a cylindrical plastic barrel with a diameter of 30 cm and a height of 150 cm. In order to facilitate sampling, inside the vertical device was a plastic water belt of 30 cm in diameter and the soil was filled in the plastic water belt. The lower end of the plastic water belt was sealed and four round holes were cut using scissors (Fig. 1).

Soil Characteristics

The soil was chernozem, with physical and chemical properties characterized by a pH of 7.8, effective phosphorus of 13.69 mg·kg^{-1}, alkali-hydrolyzed nitrogen of 134 mg·kg^{-1}, available potassium of 204 mg·kg^{-1}, and organic matter of 32.8 g·kg^{-1}. The soil was screened before pouring into the devices to remove grass root, tree root and large granular clods and stones. Then the soil were filled into the device (1.15×10^2 kg·m^{-3} in density).

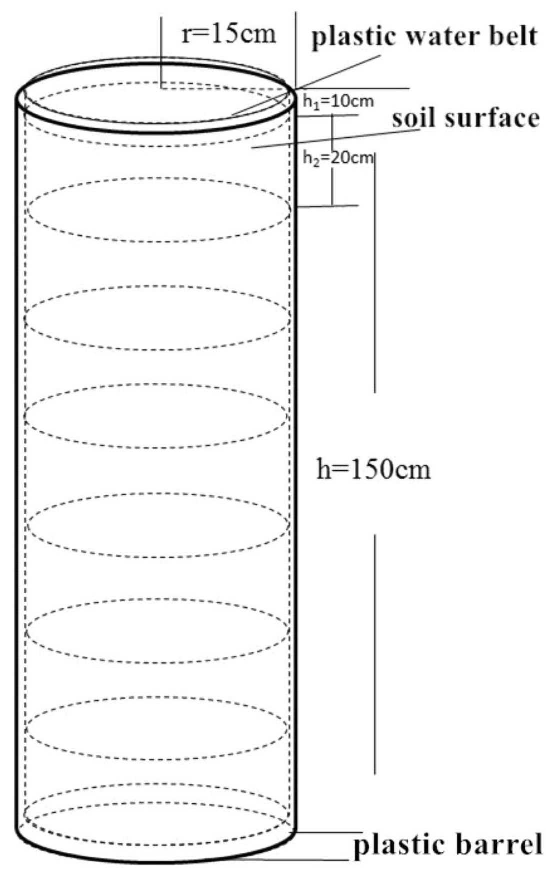

Fig. 1 Cylindrical plastic barrel with a diameter of 30 cm and a height of 150 cm

Experiment Design, Species and Seeding

Mung bean cultivar Jilv7 (drought resistance) and Gonglv2 (non-drought resistance) were planted at five seeds per device, separately. Two seedlings were retained, and grown with four replicates per growth stage. Uniconazole was evenly sprayed on the upper and lower surfaces of the leaves at V3 stage (30 mg·L^{-1}). When solution was suspended but not dripping, stopping spraying.

Measurement of Leaf Photosynthesis

Photosynthetic indicators were measured at R5 (seed filling stage) and R6 stages (full seed stage). Selecting the inverted three fully expanded leaves with consistent growth status, and using CID340 photosynthesis instrument produced by the American CID company to determine stomatal conductance (Gs), transpiration rate (Tr), net photosynthesis rate (Pn) and intercellular carbon dioxide concentration (Ci). The SPAD-502 chlorophyll meter was used to determine SPAD value of the three leaves of inverted three leaves, and the mean value was calculated as final SPAD value.

Root Sample Collection

Root samples were collected from the devices at R5 (64th days after sowing) and R6 (77th days after sowing). The upper soil surface was taken as the starting point to obtain soil samples with root in 0–20, 20–40, 40–60, 60–80 and 80–100 cm soil layers, respectively. The plants were clipped at cotyledons by scissors before sampling. Soil samples containing root were soaked in a plastic bucket filled with water until the soil became soft and then filtered. The obtained root samples were washed with clean tap water and then placed in a plastic, sealable bag, and the bag was placed in a refrigerator for further use.

Data Collection

The harvested root samples were placed in a clear glass tray filled with water. The roots were washed to remove soil particles and other dirt that could hamper efficient scanning of root samples. The glass tray was placed on a scanner (Epson V700) and digital images were generated at 400 dpi. Digital image analysis of root samples was conducted using WinRHIZO (version 2014a, Reagent Instruments Inc., Quebec, Canada) to get data of root length, from which root length density (RLD) were estimated as follows:

$$\mathrm{RLD} = L/V_0$$

$$V_0 = \pi r^2 h$$

where L is root length, V_0 is soil volume, r is radius, and h is height.

After scanning, the roots were removed from glass tray and subsequently were placed in an oven at 105 °C for 2 h, then drying to constant weight in 75 °C oven. The dry weight of roots was obtained by analytical balance and the root dry weight density (RDWD) was estimated as:

$$\mathrm{RDWD} = M/V_0$$

$$V_0 = \pi r^2 h$$

where M is root dry weight.

Statistical Analysis

Difference between treatment and control was determined by LSD test. Pearson Correlation Analysis was used to evaluate the relationships between different traits by SPSS 22. Figure preparation was carried out by MicroCal Origin software 2017 (OriginLab).

Results

Effects of Uniconazole on Stomatal Conductance of Mung Bean Leaves

At R5, the stomatal conductance of S-Jilv7 was greater than that of CK-Jilv7; S-Gonglv2 also had a greater stomatal conductance than CK-Gonglv2. At R6, the stomatal conductance of S-Gonglv2 was greater than that of CK-Gonglv2; The stomatal conductance of S-JiLv7 was significantly higher than that of CK-Jilv7 by 71.05% (Fig. 2).

Effects of Uniconazole on Transpiration Rate of Mung Bean Leaves

At R5, S-Jilv7 had a significantly greater transpiration rate than CK-Jilv7 by 34.22%, and the transpiration rate of S-Gonglv2 was significantly higher than that of CK-Gonglv2 by 228.46%. At R6, S-Jilv7 had a significantly greater transpiration rate than CK-Jilv7 by 51.08%; S-Gonglv2 had a greater transpiration rate than CK-Gonglv2 (Fig. 3).

Effects of Uniconazole on Net Photosynthetic Rate of Mung Bean Leaves

At R5, S-Jilv7 had a greater net photosynthetic rate that CK-Jilv7, but the net photosynthetic rate of CK-Gonglv2 was

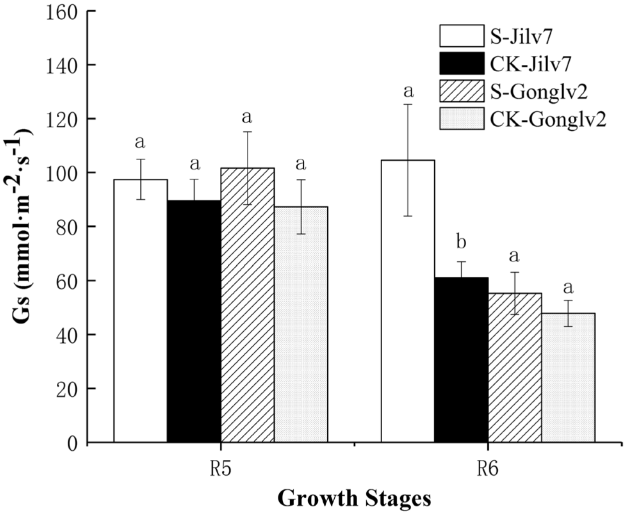

Fig. 2 Effects of uniconazole on stomatal conductance of mung bean leaves at R5 and R6 stages. Gs (stomatal conductance), S-Jilv7 (the uniconazole treatment of mung bean cultivar Jilv7), CK-Jilv7 (the control of mung bean cultivar Jilv7), S-Gonglv2 (the uniconazole treatment of mung bean cultivar Gonglv2), CK-Gonglv2 (the control of mung bean cultivar Gonglv2); Data represent average ± standard error. Significant at the 0.05 probability level

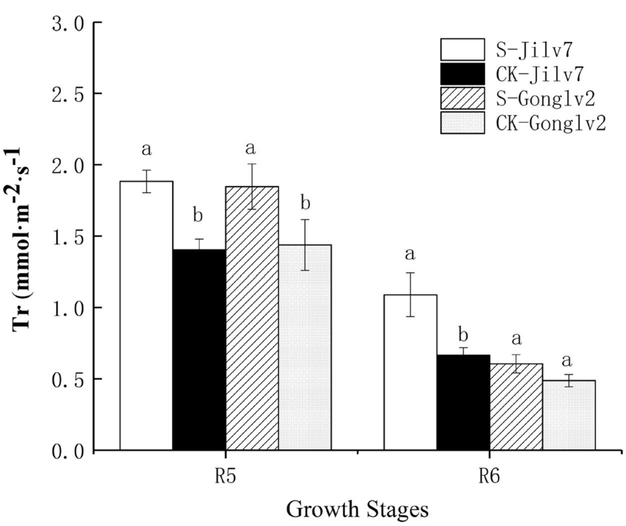

Fig. 3 Effects of uniconazole on transpiration rate of mung bean leaves at R5 and R6 stages. Tr (transpiration rate), S-Jilv7 (the uniconazole treatment of mung bean cultivar Jilv7), CK-Jilv7 (the control of mung bean cultivar Jilv7), S-Gonglv2 (the uniconazole treatment of mung bean cultivar Gonglv2), CK-Gonglv2 (the control of mung bean cultivar Gonglv2); Data represent average ± standard error. Significant at the 0.05 probability level

greater than that of S- Gonglv2. At R6, the net photosynthetic rate of S-Jilv7 was greater than that of CK- Jilv7, and

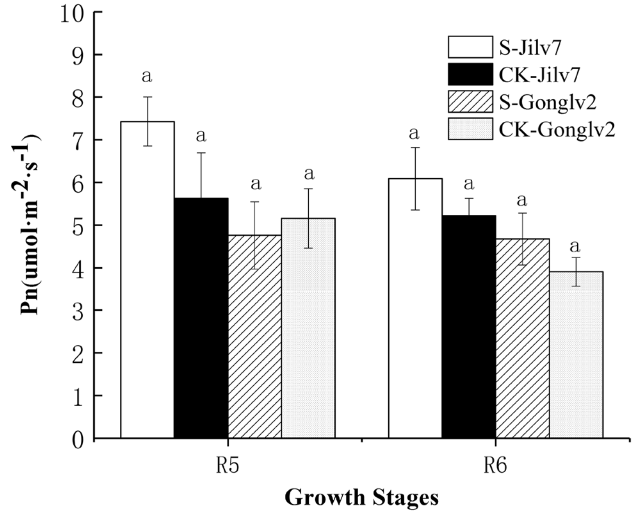

Fig. 4 Effects of uniconazole on net photosynthetic rate of mung bean leaves at R5 and R6 stages. Pn (net photosynthetic rate), S-Jilv7 (the uniconazole treatment of mung bean cultivar Jilv7), CK-Jilv7 (the control of mung bean cultivar Jilv7), S-Gonglv2 (the uniconazole treatment of mung bean cultivar Gonglv2), CK-Gonglv2 (the control of mung bean cultivar Gonglv2); Data represent average ± standard error. Significant at the 0.05 probability level

the net photosynthetic rate of S-Gonglv2 was greater than that of CK- Gonglv2 (Fig. 4).

Effects of Uniconazole on Intercellular Carbon Dioxide Concentration of Mung Bean Leaves

CK-Gonglv2 had a greater intercellular carbon dioxide concentration than S-Gonglv2 at R5 and R6, but the intercellular carbon dioxide concentration of CK-Jilv7 was less than those of S-Jilv7, and the intercellular carbon dioxide concentration of S-Jilv7 was significantly higher than that of CK-Jilv7 by 32.05% at R5 (Fig. 5).

Effects of Uniconazole on SPAD Value of Mung Bean Leaves

At R5, S-Jilv7 and S-Gonglv2 had greater SPAD value than CK-Jilv7 and CK-Gonglv2, respectively. At R6, S-Jilv7 had a greater SPAD value than CK-Jilv7; But the SPAD value of CK-Gonglv2 was greater than that of S-Gonglv2 (Fig. 6).

Correlation Between Different Photosynthetic Traits

The photosynthetic traits of mung bean leaves at R5 and R6 were significantly positively correlated with each other. SPAD values were positively correlated with all photosynthetic traits at R5 and R6; The SPAD value of mung bean leaves was significantly positively correlated with net photosynthetic rate at R6 ($r = 0.722^*$) (Table 1).

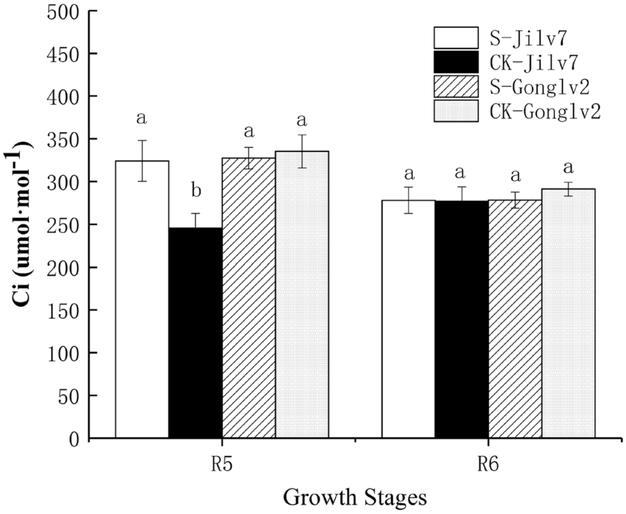

Fig. 5 Effects of uniconazole on intercellular carbon dioxide concentration of mung bean leaves at R5 and R6 stages. Ci (intercellular carbon dioxide concentration), S-Jilv7 (the uniconazole treatment of mung bean cultivar Jilv7), CK-Jilv7 (the control of mung bean cultivar Jilv7), S-Gonglv2 (the uniconazole treatment of mung bean cultivar Gonglv2), CK-Gonglv2 (the control of mung bean cultivar Gonglv2); Data represent average ± standard error. Significant at the 0.05 probability level

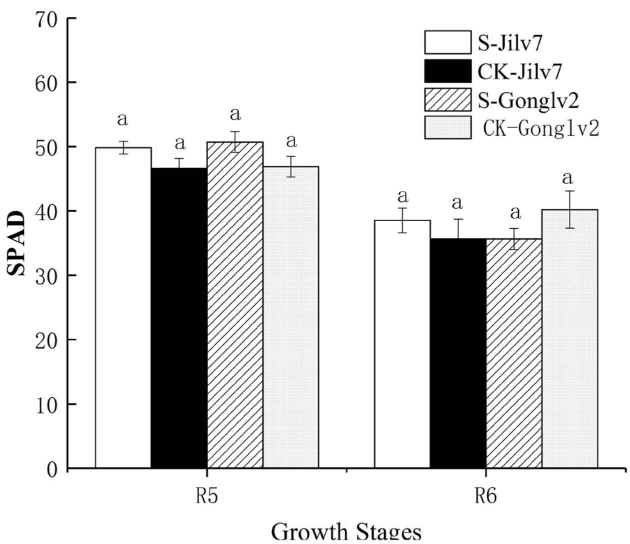

Fig. 6 Effects of uniconazole on SPAD value of mung bean leaves at R5 and R6 stages. S-Jilv7 (the uniconazole treatment of mung bean cultivar Jilv7), CK-Jilv7 (the control of mung bean cultivar Jilv7), S-Gonglv2 (the uniconazole treatment of mung bean cultivar Gonglv2), CK-Gonglv2 (the control of mung bean cultivar Gonglv2); Data represent average ± standard error. Significant at the 0.05 probability level

Table 1 Correlation between different photosynthetic traits

	Pn	Gs	Ci	Tr	SPAD
Pn	1	0.708a	0.650a	0.562a	0.682
Gs	0.895a	1	0.746a	0.968a	0.409
Ci	0.640a	0.893a	1	0.858a	0.473
Tr	0.868a	0.995a	0.883a	1	0.213
SPAD	0.722a	0.552	0.146	0.561	1

Data represent average of 4 replicates ± standard error. Distinct letters in the row indicate significant differences at the 0.05 probability level. Upper right, R5; Lower left, R6

Effects of Uniconazole on Root Length Density Distribution of Mung Bean

At R5, CK-Jilv7 had greater root length density than S-Jilv7 in 0–20 and 40–60 cm soil layers, and the root length density of CK-Jilv7 in 0–20 cm soil layer was significantly higher than that of S-Jilv7 by 16.18%; In 20–40, 60–80 and 80–100 cm soil layers, S-Jilv7 had greater root length density than CK-Jilv7. CK-Gonglv2 had greater root length density than S-Gonglv2 in each soil layer at R5.

At R6, S-Jilv7 had a greater root length density than CK-Jilv7 in 0–20 cm soil layer; In other soil layers, the root length density of CK-Jilv7 were greater than those of S-Jilv7. In 60–80 cm soil layer, S-Gonglv2 and CK-Gonglv2 had the same root length density; In 0–20, 20–40, 40–60 and 80–100 cm soil layers, the root length density of S-Gonglv2 were greater than those of CK-Gonglv2.

With the increase of soil layer depth, root length density showed a decreasing trend, and the greatest root length density was in 0–20 cm soil layer (Table 2).

Effects of Uniconazole on Root Dry Weight Density Distribution of Mung Bean

As the depth of soil layer increased, the ratio of root dry weight of mung bean control in different soil layers to total root dry weight were 69, 14, 9, 5 and 3%, respectively, and the ratio of root dry weight of mung bean treatment in different soil layers to total root dry weight were 66, 16, 10, 5 and 3%, respectively.

At R5, S-Jilv7 had greater root dry weight density than CK-Jilv7 at 20–40 and 40–60 cm soil layers; The root weight density of S-Jilv7 was significantly higher than that of CK-Jilv7 by 67.19% in 20–40 cm soil layer; In 0–20, 60–80 and 80–100 cm soil layers, CK-Jilv7 had greater root dry weight density than S-Jilv7. CK-Gonglv2 had greater root dry weight density than S-Gonglv2 in 0–20, 20–40 and 40–60 cm soil layers at R5; In other soil layers, the root dry weight density of S-Gonglv2 were greater than those of CK-Gonglv2.

At R6, S-Jilv7 in each soil layer had a greater root dry weight density than CK-Jilv7; In 0–20 cm soil layer, the root dry weight density of S-Jilv7 was significantly higher than that of CK-Jilv7 by 37.19%. In 0–20, 20–40 and 40–60 cm soil layers, S-Gonglv2 had greater root dry weight density than CK-Gonglv2; In other soil layers, the root dry weight density of CK-Gonglv2 were greater than those of S-Gonglv2 (Table 3).

Effects of Uniconazole on Yield and Yield Components of Mung Bean

The hundred grain weight and yield per plant of S-Jilv7 were greater than those of CK-Jilv7, but CK-Jilv7 had greater pods number per plant and seeds number per pod than S-Jilv7. The hundred grain weight and yield per plant of S-Gonglv2 were greater than those CK-Gonglv2, but CK-Gonglv2 had greater pods number per plant and seeds number per pod than S-Gonglv2 (Table 4).

Table 2 Root length density (cm·cm^{-3}) of mung bean cultivars Jilv7 and Gonglv2 in different soil layers at R5 and R6 growth stages

Growth stages	Cultivars	Soil layers (cm)				
		0–20	20–40	40–60	60–80	80–100
R5	S-Jilv7	0.272 ± 0.036a	0.145 ± 0.019a	0.052 ± 0.015a	0.068 ± 0.009a	0.055 ± 0.011 a
	CK-Jilv7	0.316 ± 0.093b	0.112 ± 0.019a	0.074 ± 0.012a	0.059 ± 0.006a	0.049 ± 0.005 a
	S-Gonglv2	0.187 ± 0.031a	0.109 ± 0.010a	0.062 ± 0.013a	0.039 ± 0.004a	0.029 ± 0.019 a
	CK-Gonglv2	0.192 ± 0.043a	0.127 ± 0.029a	0.090 ± 0.012a	0.077 ± 0.018a	0.060 ± 0.022 a
R6	S-Jilv7	0.196 ± 0.019a	0.112 ± 0.005a	0.079 ± 0.017a	0.020 ± 0.007a	0.016 ± 0.002 a
	CK-Jilv7	0.183 ± 0.031a	0.117 ± 0.016a	0.080 ± 0.011a	0.044 ± 0.012a	0.023 ± 0.010 a
	S-Gonglv2	0.187 ± 0.031a	0.109 ± 0.010a	0.062 ± 0.013a	0.039 ± 0.004a	0.029 ± 0.019 a
	CK-Gonglv2	0.160 ± 0.020a	0.073 ± 0.008a	0.054 ± 0.006a	0.039 ± 0.012a	0.015 ± 0.007 a

Data represent average of 4 replicates ± standard error. Distinct letters in the row indicate significant differences at the 0.05 probability level

Table 3 Root dry weight density (g·m^{-3}) of mung bean cultivars Jilv7 and Gonglv2 in different soil layers at R5 and R6 growth stages

Growth stages	Cultivars	Soil layers (cm)				
		0–20	20–40	40–60	60–80	80–100
R5	S-Jilv7	51.33 ± 5.23a	15.23 ± 2.04a	9.11 ± 1.77a	2.76 ± 0.09a	0.28 ± 0.04a
	CK-Jilv7	60.41 ± 3.45a	9.11 ± 1.59b	6.60 ± 0.13a	4.56 ± 0.40a	3.56 ± 0.55a
	S-Gonglv2	52.71 ± 6.45a	13.21 ± 2.56a	8.20 ± 1.54a	4.93 ± 0.78a	5.29 ± 1.43a
	CK-Gonglv2	65.29 ± 7.18a	15.93 ± 3.74a	10.49 ± 3.06a	1.22 ± 0.46a	1.13 ± 0.06a
R6	S-Jilv7	64.45 ± 4.62a	13.26 ± 1.89a	7.42 ± 1.23a	6.36 ± 0.19a	3.63 ± 0.16a
	CK-Jilv7	46.98 ± 2.64b	8.92 ± 1.41a	5.50 ± 0.60a	2.90 ± 1.04a	2.14 ± 0.71a
	S-Gonglv2	65.63 ± 6.32a	14.47 ± 2.87a	8.86 ± 1.41a	4.12 ± 0.55a	2.22 ± 0.54a
	CK-Gonglv2	57.96 ± 6.74a	12.66 ± 1.91a	8.19 ± 2.04a	7.45 ± 1.41a	4.72 ± 0.34a

Data represent average of 4 replicates ± standard error. Distinct letters in the row indicate significant differences at the 0.05 probability level

Table 4 Effects of uniconazole on yield and yield components of mung beans

Cultivars	Pods number per plant	Seeds number per pod	Hundred grain weight (g)	Yield per plant (g)
S-Jilv7	12.85 ± 2.25a	9.67 ± 0.74a	6.82 ± 0.55a	9.28 ± 1.72a
CK-Jilv7	13.06 ± 1.85a	9.97 ± 0.56a	6.73 ± 0.45a	9.14 ± 1.65a
S-Gonglv2	11.05 ± 1.33a	10.02 ± 1.26a	6.90 ± 0.63a	9.79 ± 1.96a
CK-Gonglv2	11.36 ± 0.66a	10.38 ± 0.61a	6.61 ± 0.41a	8.86 ± 0.81a

Data represent average of 4 replicates ± standard error. Distinct letters in the row indicate significant differences at the 0.05 probability level

Table 5 Correlation between photosynthetic indicators of mung bean and yield at R5 and R6 stages

Stages	Pn	Ci	Gs	Tr	SPAD
R5	0.634	− 0.463	0.345	− 0.235	0.684
R6	0.108	0.423	− 0.431	0.537	0.347

Data represent average of 4 replicates ± standard error. Distinct letters in the row indicate significant differences at the 0.05 probability level

Table 6 Correlation between mung bean root in different soil layers and yield at R5 and R6 stages

Growth stage	Soil layer	Root length density	Root dry weight density
R5	0–20	0.780	0.728
	20–40	0.183	0.938*
	40–60	0.624	0.559
	60–80	0.043	0.210
	80–100	0.228	0.401
R6	0–20	0.544	0.696
	20–40	0.625	0.891*
	40–60	0.467	0.335
	60–80	0.105	0.621
	80–100	0.374	0.324

Data represent average of 4 replicates ± standard error. Distinct letters in the row indicate significant differences at the 0.05 probability level

Correlation Between Photosynthetic Indicators and Yield

At R5, the net photosynthetic rate, stomatal conductance and SPAD value of mung bean were positively correlated with yield, and the SPAD value and yield had the greatest correlation coefficient. The intercellular carbon dioxide concentration and transpiration rate were negatively correlated with yield, respectively.

At R6, except stomatal conductance, the net photosynthetic rate, intercellular carbon dioxide concentration, SPAD value were positively correlated with yield of mung bean, and the transpiration rate and yield had the greatest correlation coefficient (Table 5).

Correlation Between Root and Yield

At R5, the root length density and root dry weight density of mung bean in different soil layers were positively correlated with yield; In 0–20 cm soil layer, root length density had the greatest correlation with yield; In 20–40 cm soil layer, root dry weight density and yield were significantly positively correlated (r = 0.938*).

At R6, both of the root length density and root dry weight density of mung bean in different soil layers were positively correlated with yield; The root dry weight density in 20–40 cm soil layer and yield were significantly positively correlated (r = 0.891*) (Table 6).

Discussion

Stomatal conductance was one of the parameters reflecting photosynthesis of plants (Miner et al. 2017). The greater stomatal conductance of plant leaves, the higher carbon dioxide content in the cells and the higher carbon dioxide content available for photosynthesis, resulting in an increase in photosynthetic rate. In this study, we found uniconazole increased stomatal conductance of two mung bean cultivars at R5 and R6. This was consistent with result of Yan et al. (2015) who found soybean with uniconazole raised stomatal conductance at R5. And we also found uniconazole had a regulatory effect on transpiration rate of mung bean leaves, in which the transpiration rate of mung bean leaves were improved at R5 and R6. But this result was contrary to the study of Duan et al. (2010) who found that uniconazole reduced the stomatal conductance of wheat leaves at seed filling stage (R5 is seed filling stage for legume) and maintained the transpiration rate. The reason may be that different crops have different levels of response to uniconazole, optimal preparations and application methods. The increase in transpiration rate was beneficial to reduce temperature of the leaves and avoid leaves from being burned by high temperature due to strong sunlight (Wuenscher and Kozlowski 2010). Transpiration was also a major driving force for absorption and transport of water by plants (Manzoni et al. 2013), especially tall plants. Meanwhile, since mineral salts (inorganic salts) had to be dissolved in water in order to be absorbed and operated by plants, then minerals were absorbed and distributed into the various parts of the plant body along with the absorption and flow of water. Thus, an increase in transpiration rate would help transport both substances through the plant.

The SPAD value represented the relative content of chlorophyll in the leaves (Eszter et al. 2019). In this study, we found that uniconazole had different regulatory effects on SPAD value of different mung bean varieties. The result showed that uniconazole increased the SPAD value of Jilv7 at R5 and R6. But for Gonglv2, only SPAD value at R5 was promoted. As we knew, chlorophyll was one of the most important pigments related to photosynthesis (Bettini et al. 2016). As the reaction site of plant photosynthesis, chlorophyll provided an environment for electron transport and photophosphorylation (Herbst et al. 2018). Chlorophyll absorbed energy from light, which was then used to convert carbon dioxide into carbohydrates. The increase in chlorophyll content was very helpful to increase the light saturation point. Within a certain range, photosynthetic products can be increased. Based on the above important significance of chlorophyll for plants, the application of uniconazole can give Jilv7 a higher photosynthetic potential at R5 and R6. At the same time, we found that the SPAD value of mung bean at R5 had the greatest correlation with yield with a correlation coefficient of 0.684 compared with other photosynthetic indicators. This meant that this indicator was of great significance for increasing mung bean yield.

Root length density refered to the length of the roots per unit volume of soil at a specific depth, and it represented the proportion of the soil volume that supplied nutrients to root system (Moyassar et al. 2016). When root length density increased, the surface area for water absorption also increased, thereby shortening the distance of soil water transmission, which was beneficial to water absorption. In this study, the greatest root length density was found in 0–20 cm soil layer, and with the increase of soil layer depth, root length density decreased. This was consistent with the findings of Gao et al. (2010) in soybean. The distribution pattern of root length density indicated that water absorbed by mung bean roots mainly came from the upper soil layer, especially the 0–20 cm layer, in which the root length density was larger. Compared with upper soil layer, water supply from the deeper soil layer was likely to be auxiliary, such as the 80–100 cm soil layer in which root length density was only 0.015–0.060 cm·cm^{-3}. However, this did not mean that roots from deeper soil had a weaker water absorption capacity than the roots from upper soil layer.

According to the distribution of root dry weight density, we found root dry weight density gradually decreased with the increase of soil layer depth. This was consistent with the distribution pattern that Benjamin and Nielsen (2006) found in soybeans. By spraying solution of uniconazole at V3, we found the proportion of root dry weight in 0–20 cm soil layer was reduced, while the root dry weight in 20–40 and 40–60 cm soil layers were increased, and no change happened in proportion of root dry weight in the soil layer below 60 cm. In addition, we also found root dry weight density of mung bean in 20–40 cm soil layer had a significantly positive correlation with yield ($r = 0.938^*$ at R5; $r = 0.891^*$ at R6). Although root dry weight density in 0–20 cm soil layer was greater than that in 20–40 cm soil layer, the degree of correlation between yield and root dry weight density in 20–40 cm soil layer was higher than that in 0–20 cm soil layer, which showed that the magnitude of root dry weight per unit soil volume couldn't absolutely reflect the level of contribution to yield. The taprots occupied a considerable part in 0–20 cm soil layer. As the soil depth increased, the taprots gradually became thinner, and the lateral roots, whose diameter was much thinner than that of the taprots, gradually increased. Thinner roots leaded to a larger surface-to-volume ratio. By having a large surface area and low volume, it increased the efficiency of absorption of minerals and water. This may be the reason why the correlation between root dry weight density in 20–40 cm soil layer and yield was higher than that in 0–20 cm soil layer.

Conclusion

The application of uniconazole at V3 effectively improved the conditions required for photosynthesis to a certain extent and regulated the proportional distribution of root system in different soil layers, which promoted the absorption and transportation of water and inorganic salts. Based on the distribution pattern of decreasing root length density from top to bottom, the upper root had a potential to provide a large amount of water for mung bean growth and development.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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