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Development Status of Direct Seeding Rice and Study on Response Mechanism of Submergence

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Abstract

Direct seeding rice is one of the main ways of light and simplified cultivation, but the seedling formation process of direct seeding seeds is affected by the germination environment. When rice seeds are submerged for a long time, it will generally lead to difficulties in rice germination, germination, emergence, and seedling leveling, and more seriously lead to rotten seeds, rotten buds, and rotten seedlings, affecting the growth, development, and yield of rice. Different studies have shown that submergence and hypoxia stress have the same effect on the germination and growth of rice. Submergence conditions would cause oxygen deficit in rice seeds, and then promote the seeds to show a unique response. This paper summarized the development status of direct seeding rice, the growth of seedling coleoptile under submergence and the impact of oxygen deficiency on rice root growth, compared and analyzed the advantages and disadvantages of direct seeding rice and traditional rice planting, and discussed the key problems faced by direct seeding rice and the physiological and biochemical activities of roots in the growth process. On this basis, this paper prospects for the development of direct seeding rice in the future, which can provide important reference for the large-scale production of direct seeding rice.

Subject Areas

Agricultural Science, Environmental Sciences

Keywords

Rice, Direct Seeding, Morphogenesis, Root Development, Oxygen Deficit, Submergence Tolerance Mechanism

1. Introduction

Rice is the main food crop in China. The safe production of rice is directly related to national food security. China's traditional rice planting is mainly artificial seedling raising and seedling planting, which is cumbersome, time-consuming, and labor-intensive. Direct seeding of rice seeds directly into the field is a light and simple planting method, which eliminates multiple processes such as seedling raising, seedling pulling, seedling transportation and transplanting. It has the characteristics of saving labor and cost, saving water resources, saving land, and reducing the labor intensity and improving economic benefits of rice planting. It is gradually becoming an ideal light, simple and efficient cultivation mode of modern rice. With the development of rice direct seeding cultivation technology in recent years, researchers had carried out a lot of exploration, improvement, and experience accumulation on different rice direct seeding cultivation methods. At present, there are mainly dry direct seeding, dry direct seeding aquatic and dry-wet alternate growth of rice. Different water management methods also had different effects on the later growth of rice [1]. However, different natural conditions and production technologies in different regions lead to different effects of direct seeding rice production, and some problems are gradually emerging. Water accumulation and lodging are the two major problems that threaten the yield of direct seeding rice. Varieties with strong lateral root branching ability, more adventitious roots and deeper rooting depth are more suitable for direct seeding. It is the simplest and most effective way to solve this problem by variety selection [2]. Therefore, this paper intends to provide theoretical reference and ideas for the breeding of direct-seeded rice varieties by introducing the appearance of embryo sheath, root morphogenesis and physiological metabolism of direct-seeded rice under flooded conditions.

2. Development Status of Direct Seeding Rice

2.1. Development of Direct Seeding Rice in China

With the rapid development of China's economy, a large number of labor force has shifted from rural areas to cities, and the direct seeding cultivation area of rice is increasing year by year, which has been rapidly promoted in Shanghai, Anhui, Jiangsu and other places [3] [4]. This plays an important role in solving the shortage of rural labor resources in the process of rice production, promoting sustainable rice production and increasing farmers' income. The development of direct seeding rice production has become an objective need [5]. The perennial planting area of rice in China is about 30 million Hm^2, accounting for about 1/3 of the total grain output [6]. Affected by factors such as rural labor transfer, rising labor costs, rising prices of agricultural means of production and weak food prices, farmers' demand for light and simplified rice planting methods was becoming stronger and stronger [7]. Rice direct seeding is a light and simplified planting method, which eliminates the operation links such as seedling raising, seedling lifting, seedling transportation and transplanting. It is very popular with farmers. About 30% of rice planting in China adopts direct seeding [8]. There are two varieties of direct seeding of rice in China: manual seeding and mechanical seeding. The direct seeding seedlings were distributed disorderly in the field. Mechanical direct seeding can sow rice seeds into the field in rows or holes through furrow and ridge, so as to realize orderly planting. Mechanical direct seeding of rice is mainly divided into mechanical dry direct seeding and mechanical water direct seeding. Mechanical dry direct seeding is mostly used in rice areas in northern China, which can complete the combined operation of ditching, ridging, sowing, and soil covering at one time; Mechanical water direct seeding is mostly used in southern rice areas, which can realize the combined operation of ditching, ridging, hole sowing or drill sowing at one time. It could be seen that direct seeding of rice is widely used.

2.2. Development Status of Rice Direct Seeding in the World

At present, the planting area of direct seeding rice accounts for about 1/3 of the rice planting area in the world, among which the direct seeding area accounts for a large proportion in developed countries such as the United States, Australia and Europe. The rice planting process in these countries is relatively short, and the developed industrialization makes its labor cost too high, so the direct seeding cultivation method of rice came into being. The Mechanized Direct Seeding Methods of rice adopted by these countries include dry direct seeding and water direct seeding [9]. Dry direct seeding generally uses a direct seeding machine to sow the seed soaked and coated "Blind Valley" in the dry field without water layer after land preparation, with a seeding rate of 30 grains per square foot and 15 - 20 seedlings. A 9-meter-wide planter can sow more than 2500 acres a day. Water direct seeding is to establish a water layer after land preparation, and then spread the sprouting seeds in the flooded rice field by aircraft. The daily sowing amount of each aircraft is more than 4000 acres. The planting area of rice in the United States is about 1.1 square meters × 10^6 ha, 100% of which adopts direct seeding cultivation, of which 80% is dry direct seeding and 20% is water direct seeding. Direct seeding cultivation has greatly improved the efficiency of rice production and the degree of large-scale production in the United States. At present, there are only about 6000 farmers engaged in rice production in the United States, with a per capita rice planting area of 180 hm^2 and a yield of more than 8 t/hm^2. The total man hours from rice planting to harvest are 36 times more efficient than in Asia [10]. The total rice planting area in Europe is about 4.6 hectares × 10^5 ha, the output is about 6.5 t/hm^2. After the end of the Second World War, most European countries generally began to adopt mechanized direct seeding for rice production, and the proportion of direct seeding rice area in the total area of rice is gradually increasing. The country with the largest rice planting area is Italy, which is about 2.4% × 10^5 ha, the total annual output of rice is about 1.3 × 10^6 t, accounting for about 40% of the total rice production in Europe. The degree of mechanization of rice production in Italy is very high. All production links such as land tillage, planting, weeding, and harvesting were mechanized in the 1970s. After the 1960s, mechanized direct seeding was basically adopted. Only 2% were traditional transplanting and planting, and the coverage of mechanized direct seeding is quite high [7]. Other developed countries, such as Australia, also have a large area of direct seeding rice, accounting for about 81% [11]. Direct seeding rice was planted abroad earlier and covers a wide area. Japan is one of the countries that studied direct seeding rice earlier. With the continuous improvement of industrialization, the labor force engaged in agriculture in Japan had gradually decreased. In this context, the direct-seeding cultivation mode of provincial workers had again received attention to the rapid development of rice production in Japan. From the 1960s to the early 1970s, the development of herbicide promoted the improvement of direct seeding rice production technology, which led to the steady development of direct seeding rice in Japan. Subsequently, due to the rapid promotion and wide application of mechanical transplanting technology, rice production can also be greatly reduced, especially the labor intensity of rice transplanting, and the area of direct seeding rice showed a downward trend. Since then, Japan had increased its research on direct-seeding rice cultivation techniques, and various direct-seeding machines had also been applied and promoted. The development of high-efficiency herbicides and the improvement of direct-seeding cultivation techniques had provided strong technical support for the development of direct-seeding rice. The direct-seeding cultivation of Japanese rice had become practical and mechanized, and the area of direct-seeding rice in Japan had been increasing in the 21st century [12].

2.3. Development Advantages of Direct Seeding Rice

Advantage 1: time saving and labor saving. Compared with the traditional seedling raising and transplanting method, direct seeding of rice mostly uses sowing or machine direct seeding, which saves the time of seedling raising. Broadcast or machine broadcast has high efficiency and small amount of labor. Compared with manual transplanting, the labor efficiency can be increased by more than 1.5 times, which is more suitable for large-scale operation. In the current situation that many rural labor forces go out to work, direct seeding cultivation technology can solve the problems of shortage of rural labor force and difficult employment [13].

Advantage 2: saving production cost. Direct seeding of rice saves the link of seedling raising, and it is directly sown in the field without seedling raising and special seedling field. In areas where there is no contradiction between previous and subsequent crops in one crop a year, it can improve the land utilization rate. In areas where the contradiction between multiple cropping seasons is not prominent, it can reduce the yield loss of previous crops that cannot be planted due to reserved seedling field, and save the need to make seedling field, agricultural film Labor and material costs such as fertilizer. The direct seeding operation is simple and fast, the time is short, the labor volume is small, the production cost is greatly reduced, the input-output rate is increased, the unit input-output rate is 20% - 25% higher than that of transplanting, and the economic benefit is significantly increased [14].

Advantage 3: shorten the growth period. Due to the process of direct seeding cultivation without seedling pulling (or machine transplanting) root cutting and returning to green and living trees after transplanting, it can tiller early, accelerate growth and development, increase the number of effective panicles, reduce the total number of grains per panicle, and shorten the filling, fruiting, and ripening time accordingly, so the whole growth period of direct seeding rice is relatively shortened. Generally, the growth period of direct seeding rice is about 10 days shorter than that of transplanting rice sown at the same time with the same variety (combination). For areas with multiple cropping system and tight production stubble, as long as the variety matching is appropriate, it is conducive to stubble connection and high yield throughout the year [15].

Advantage 4: Avoiding labor peak time. Direct seeding rice cultivation operation time is different from transplanting rice, land preparation, flat, weeding, and other agricultural operation time is not limited, can make full use of family labor [16].

2.4. Problems and Countermeasures in the Development of Direct Seeding Rice

Although direct seeding rice has many advantages, it still faces some problems, such as difficult to get the whole seedlings, rotten roots and buds, serious insect pest, serious occurrence of weedy rice, shallow root rooting, easy lodging, poor high and stable yield and so on. Among them, the low rate of full seedling and full seedling is the primary problem of low and unstable yield of direct seeding rice. Moreover, the sowing amount of direct seeding rice is relatively large, with dense roots and poor adhesion. In the later stage, it is easy to cause shade, poor ventilation effect, weak photosynthesis and prone to lodging, which seriously affects the yield and quality [17]. Improve the quality of land preparation, level paddy fields, build drainage ditches to prevent uneven ponding in the field after sowing, overcome the problems of rotten seeds and uneven emergence after sowing, and strengthen the breeding of new varieties of direct seeding rice. In order to obtain direct seeding rice with flood resistance, vigorous tillering at seedling stage, inhibition of weed growth, short basal internodes, deep roots, and lodging resistance. Comparison of advantages and disadvantages between direct seeding rice planting mode and traditional rice planting mode (Table 1).

3. Response Mechanism of Submergence Tolerance during Seedling Stage of Direct Seeding Rice

3.1. Coleoptile Elongation under Submergence

Under the condition of hypoxia, the coleoptile of rice is one of the few tissues

Table 1. Comparison of advantages of direct-seeding rice planting and traditional planting.

Type	Advantage	Disadvantage	References
Direct seeding rice pattern	Save work time	Rotten roots and rotten buds	Li *et al.* 2021 [18]
	Saving production cost	Serious insect pest and grass damage	Huang *et al.* 2018 [19]
	Shorten growth period	Roots are easy to fall down	Yao *et al.* 2012 [20]
Traditional rice cultivation pattern	Seeding is uniform and easy to complete seedlings	Time-consuming, laborious, and inefficient	Wang *et al.* 2006 [21]
	Rice paddy water level temperature is stable	Large amount of agricultural film in rice seedling field	Gao *et al.* 2020 [22]
	Deep roots resist collapse	Transplanting has a long growth period	Yang *et al.* 2011 [23]

that can grow. Compared with normal germination, rice seeds only grow coleoptile in flooded environment, which inhibits the growth of leaves, seeds, and roots. When rice seeds germinate under submergence, the coleoptile elongates rapidly to reach the aerobic environment in the upper layer of the water surface, which provides an oxygen source for the growth of other organs such as roots and leaves and the survival of seeds, and provides a necessary physiological and metabolic guarantee for the survival of rice [24]. However, Setter *et al.* found that excessive and rapid elongation of coleoptile does not mean that the survival rate of seedlings under submergence conditions is improved, and there is no significant correlation between the two [25]. This is because some varieties reduce the survival ability of seedlings in order to maintain the growth rate of coleoptile. In agricultural production, some places with poor drainage or uneven land often accumulate water, resulting in paddy submergence. Relying on the ability of rice seed coleoptile alone, it cannot quickly adapt to the long-term flooded environment.

3.2. Root Growth Affected by Hypoxia Stress

Oxygen is one of the necessary conditions for normal physiological metabolism and growth and development of higher plants. It is the necessary reducing force to maintain cell growth. It is the core of the whole plant life metabolism. The growth and metabolism of plant living cells requires an appropriate concentration of oxygen [26]. In actual production, hypoxia stress is often caused by uneven precipitation or improper irrigation, and the most intuitive manifestation of plants under hypoxia stress is that root growth is affected [27]. With the extension of hypoxia stress time, reducing toxic substances increased, which was not conducive to the growth of taproot and lateral root of rice seedlings. Moreover, under hypoxia stress, the root system is dominated by anaerobic respiration, resulting in the accumulation of alcohol and other anaerobic respiratory products, resulting in the death of root cells and the increase of the number of black roots; The root respiration rate decreases and the energy generated decreases, which leads to the lack of root energy, reduces root activity and respiratory intensity, and cannot ensure the generation of sufficient energy metabolism to maintain root development and nutrient absorption.

In addition, hypoxia stress can also affect the type and content of hormones. The occurrence and elongation of main and lateral roots are sensitive to auxin (IAA), and whether auxin stimulates or inhibits root growth mainly depends on the concentration of auxin. Studies have shown that, hypoxia stress induces the increase of ethylene and ABA content in roots, inhibits the transportation of aboveground IAA to roots, and leads to the accumulation of aboveground IAA [28] The accumulation of IAA at the base of stem node promotes the overgrowth of stem, which makes the content of IAA in root very low, and then inhibits the elongation of fine root (root diameter is 0.05 - 1 mm). This part of root is also called active root, which is the main tissue for plants to absorb water and nutrition from soil [29]. Therefore, the reduction of this part of root will affect the absorption and accumulation of nutrient elements in the environment, and then affect the life activities of the plant itself. Roots are also the main organs for plants to absorb nutrients and water. The growth and development of aboveground plants are directly or indirectly affected by root morphology [30].

3.3. Root Morphogenesis of Seedlings Affected by Hypoxia Stress

The morphogenesis of seedling roots is the key factor to determine the survival of seedlings. Under submergence stress, the root is the first organ to face hypoxia stress, with significant growth damage and phenotypic changes [31]. Sun *et al.* found that after submergence, the root system will be in an extremely anoxic state, and the aerobic respiration of cells will change into anaerobic respiration, resulting in the massive accumulation of respiratory products such as ethanol and acetaldehyde, resulting in the death of root cells, the increase of the number of black roots and the decrease of root activity, affecting the absorption of mineral nutrients, destroying the synthesis of chlorophyll, and reducing the photosynthesis of aboveground parts [32]. Submergence will reduce the length of taproot and root growth density of rice [33]. With the increase of flooding time, the length and number of main and lateral roots of rice will decrease and inhibit the formation of root morphology [34].

3.4. Root Respiration of Direct Seeding Rice Affected by Hypoxia Stress at Seedling Stage

Xu *et al.* concluded that the effect of short-term hypoxia stress on root respiratory intensity of rice seedlings is inhibition promotion inhibition, and the inhibition will decrease with the extension of treatment time [35]. The change trend of root activity was consistent with the respiratory intensity of root system. Nitrate Reductase (NR) activity in rice seedling roots was induced by hypoxia stress; The effect of hypoxia stress on Glutamate Dehydrogenase (GDH) activity in rice roots is related to varieties, indicating that hypoxia stress has a significant effect on rice seedling roots and there are differences among varieties [36]. Hypoxia stress changes the pathway of nitrogen metabolism, induces the increase of NR activity in roots and changes the nature of respiration, mainly anaerobic respiration. Due to the inhibition of the growth of rice seedlings by hypoxia, the respiratory rate of rice roots is reduced, the energy provided is reduced and its physiological function is reduced. In addition, rice seedlings can reduce the damage of hypoxia stress through the changes of respiratory consumption and nitrogen metabolism, so as to maintain their survival under hypoxia stress.

3.5. The Metabolic Pathway of Organic Matter of Direct Seeding Rice at Seedling Stage under Hypoxic Conditions

The change of soluble sugar and protein content is a common physiological phenomenon in stress. Under stress conditions, in order to maintain the normal physiological metabolism related to turgor, plants increase the solute content in cytoplasm by accelerating metabolic activities, reduce osmotic potential and maintain cell turgor [37]. Roots are the main organs for water absorption and nutrient uptake of plants. Whether plants can absorb water from soil depends on the water potential difference between soil and plant roots. The establishment of water potential difference depends on the transport of mineral ions, while the transport of mineral ions (iron, potassium ions, etc.) to roots requires aerobic respiration to consume sugars and release energy [38] (**Figure 1**: In the cytoplasm matrix, one molecule of glucose is decomposed into two molecules of pyruvic acid, and four molecules are removed [H] (activated hydrogen); a small amount of energy is released during glucose decomposition, part of which is used to synthesize ATP and produce a small amount of ATP. This stage does not require the participation of oxygen, and is carried out in the cytoplasm matrix, and the aerobic respiration is the same as the anaerobic respiration in the first stage. Under anoxic conditions, the cells were subjected to anaerobic respiration. In the cytoplasm matrix, pyruvic acid was decomposed into hexane alcohol, carbon dioxide and a small amount of energy. Under the action of ATPase, energy was temporarily stored in ATP. Under aerobic conditions, the cells were subjected to aerobic respiration, and the first stage was the same as that of anaerobic respiration. In the second stage, pyruvate entered the mitochondrial matrix, and the two molecules of pyruvate and hydrogen in water molecules were all removed, totally 20 [H], and pyruvate was oxidized and decomposed into carbon dioxide. In this process, a small amount of energy is released, and part of it is used to synthesize ATP to produce a small amount of energy. This phase also does not require the involvement of oxygen, which is carried out in the mitochondrial matrix. The third stage: on the inner membrane of mitochondria, a total of 24 [H] removed in the first two stages are bound to water with oxygen absorbed from the outside or generated by chloroplast photosynthesis; in this process, a large amount of energy is released, part of which is used to synthesize ATP, producing a large amount of energy. This stage requires the involvement of oxygen, carried out on the mitochondrial inner membrane). Under the condition of submergence and hypoxia, the transport of mineral ions in roots will be blocked, and organic matter

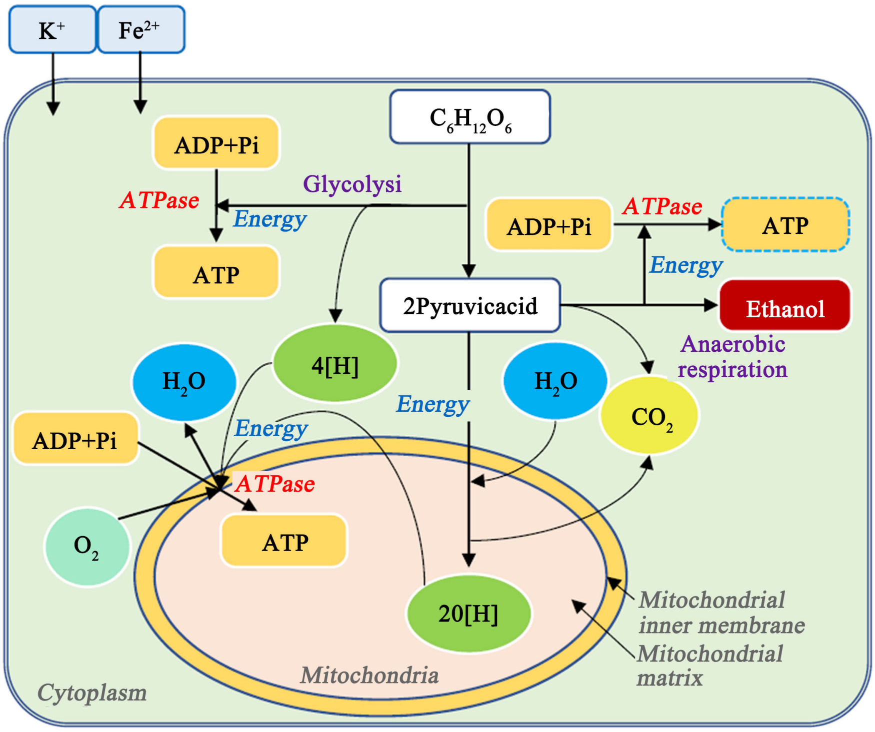

Figure 1. Metabolic diagram of root respiration.

cannot be efficiently decomposed for energy supply, resulting in the weakening of related metabolic activities and even the cessation of related life activities of seedlings.

When rice or other crops are under stress, they can reduce or repair the damage caused by stress by changing the relevant metabolic pathways in the plant or regulating the expression level of relevant proteins, so as to maintain the normal physiological activities under stress. Dehydrin is a kind of hydrophilic protein, which is widely expressed in plants under stress to improve the stress resistance of plants [39]. GNOM protein is involved in the growth and development of plant taproot and lateral root [40]. Under low temperature stress, the large expression of GNOM protein is conducive to maintain the root growth of plants. Serine/ threonine-protein kinase is an enzyme that catalyzes the phosphorylation of serine or threonine residues. It plays a key role in plant response to stress, cell signal transduction, material transportation and physiological metabolism [41]. Glycosyltransferase transfers glycosyl groups to specific receptors through catalysis, and glycosylation receptors will further participate in plant growth and development, material synthesis and stress response [42].

4. Summary and Prospect

With the continuous development of direct seeding planting methods in China, the use of direct seeding rice to develop agriculture has gradually moved from theory to application, and is making up for the shortcomings brought by traditional planting methods. This paper summarizes the advantages and disadvantages of the application of direct seeding rice and the effects of stress on the growth and metabolism of seedling coleoptile and root systems. Although most of the high-yield and high-quality rice varieties popularized in a large area of production are bred with the breeding goal of suitable transplanting, the transplanting varieties are directly used for direct seeding and lack mature supporting cultivation techniques, which often leads to various problems in production. Among them, the large number of seeds used for direct seeding, the low germination and seedling rate are the prominent problems in production. However, on the basis of fully studying the growth mechanism of seedling coleoptile and root system under the condition of flooding, combined with the actual situation of agricultural production to overcome the problem of "full seedling difficulty" in mountainous and hilly water accumulation areas, we can further develop rice varieties resources with strong waterlogging tolerance and high seeding rate, reduce the blindness of agricultural direct seeding selection, and further optimize the modern agricultural direct seeding cultivation techniques.

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Conflicts of Interest

The authors declare no conflicts of interest.

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