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Innovation of the New Superior Quality Foxtail Millet [*Setaria italica* (L.) *P.Beauv*] Variety-Jigu32 with Characteristics of Stress Resistance, Stable and High Yield and Its Physiological Mechanism

Suying Li[1], Shengjun An[2], Zhengli Liu[1*], Ruhong Cheng[1*], Zhijun Wang[2]

[1]Institute of Millet Crops, Hebei Academy of Agriculture and Forestry Sciences/National Millet Improvement Center, Shijiazhuang, China
[2]Center of Bioreactor and Protein Drug Research and Development of Hebei Universities, Hebei Chemical and Pharmaceutical College, Shijiazhuang, China
Email: [*]liuzhengli65@126.com, [*]rhcheng63@126.com

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Abstract

In main foxtail millet growing regions of China, natural disasters happen frequently, causing losses in production and finance. Therefore, it is urgently needed to breed new superior quality foxtail millet varieties with stress resistance, stable and high production, and, so as to stabilize millet production and promote millet industry development. Jigu32, a new foxtail millet variety with stable, high-yield and superior qualities, was developed using Target Character Gene Bank breeding method, and its physiological mechanism was studied as well. Results showed that the prominent characteristics of Jigu32 were as follows: 1) strong stress resistance and stable yielding; 2) high yielding; 3) rich calcium content and superior qualities; 4) excellent comprehensive characteristics. In 2010 National Foxtail Millet Regional Trials, the weather was tough. Severe drought occurred in some experimental stations while in some others, continuous rain, low temperature and little sunlight appeared. However, with the outstanding stress resistance, Jigu32 achieved the highest yields, and the yields were very stable under different conditions. Per unit yield of Jigu32 reached to 5133.3 kg/hm^2, which was the highest in the trials, increasing 9.42% compared with the controls. Calcium content of Jigu32 was 121 mg/kg in the grain, and the taste, nutrition and commodity qualities were optimal. Therefore, Jigu32 was rated as the national secondary superior quality foxtail millet. The study showed that the physiological mechanism of Jigu32's merits was based on the improved activities of peroxidase (POD), superoxide dismutase (SOD), 6 phosphate

[*]Corresponding authors.

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dehydrogenase (G6PDH), glutamine synthetase (GS) and glutamic dehydrogenase (GDH), and on its higher absorption ability and conversion efficiency of N, P, K. POD, SOD and G6PDH of Jigu32 were more active in each development phase, leading to higher resistance to adversity and aging; glutamine synthetase (GS) and glutamate dehydrogenase (GDH) of Jigu32 were more active, resulting in higher assimilation and transformation ability of nutrients. It is of great significance to promote the development of Jigu32, and it will be beneficial to sustainable, stable agricultural development, and thus orderly and stably boost the development of the millet industry in our country. The research on its physiological mechanism of stable and high yielding will provide theoretical support while breeding new stable and high-yield foxtail millet varieties later.

Keywords

Foxtail Millet; Stable Yield; High Yield; Breed; Physiological Mechanism

1. Introduction

Foxtail millet [*Setaria italica* (*L.*) *P.Beauv*] is one of the traditional Chinese crops, planted in the North, Northwest and Northeast of China. Its comprehensive and balanced nutrition and its tolerance to arid and barren soil rank it one of the most popular side crops and a part of the plan to secure China food supply. But natural calamities happen frequently in main foxtail millet growing regions. In harvest years, the supply of foxtail millet exceeds the market need, causing a fall in price, which means farmers' income doesn't increase, though they get good yields. During harsh years, the supply decreases due to poor yields, but the price doesn't increase sufficiently for people's limited consuming capability. Thus farmers' income still decreases. Lacking stable and outstanding millet varieties, foxtail millet market is chaotic and unstable. Therefore it is in urgent need to develop stable and outstanding varieties so as to stabilize the fluctuation of the production and the market in major foxtail millet planting areas, and thus to make farmers' income increase stably and sustainably.

Many important researches about foxtail millet have been conducted, such as resources preservation and target genes exploitation in USA and Japan [1], anti-herbicides germplasm innovation in France and Canada [2]-[4], development of forage foxtail millet in Australia [5], and the pure line breeding method in India [6]. But successful development of stable and high-yield varieties is rarely reported.

In China, focusing on germplasm resources and breeding, a lot of work has been done since 1949, and some varieties have been developed, such as Jigu6 [7], Yugu1 [8], Lugu10 [9], Jigu19 [10], Jigu26 [11], the quality and yields of which have been improved sufficiently. However, lacking stability under adverse conditions still remains as a crucial problem.

After years of research, the Institute of Millet Crops of Hebei Academy of Agricultural & Forestry Sciences developed a new remarkable variety, Jigu32. As years of field trials and demonstration showed, Jigu32 had very impressive ability of stress resistance, and could get stable high yield even under such adverse weather conditions as drought, low temperature, continuous raining and the lack of sunlight. The extension of Jigu32 will make major millet production areas in China achieve high yields in good years, stable yields in bad years. Its extension will play an important role in achieving the sustainable, stable development of millet production and the continuous growth of farmers' income in China.

Previous researches show that POD widely exists in plants as one of highly active enzymes, and it is related to respiration, photosynthesis, and oxidation of auxin. Its activity varies constantly in plant growth, generally more active in old tissues and weaker in tender tissues, because POD can make certain carbohydrates convert into lignin, which enhances lignification [12]. And it is also found that the activity of POD in the root of the rice of premature senescence and yield reduction increased. Then it can be concluded that POD can be used as a physiological assessment index for plant resistance to adversity.

SOD, an active substance derived from living organisms, can eliminate the harmful substances generated in the course of biological metabolism. If constantly added to organisms, SOD will have a special anti-aging effect [13]. Therefore, the activity of SOD in plants increases continuously as plant tissues develop and age, even under adverse conditions. Researches have shown that the activities of POD and SOD are closely related to plant resistance to low temperature [14]-[16] and drought [17]-[19]. G6PDH is an important restriction enzyme of the

PPP (the pentose phosphate pathway), which is able to regulate cell NADPH level and participates in many cell processes, especially playing an important role in the processes of maintaining cellular redox as well as controlling cell growth and apoptosis [20]. Thus, POD, SOD and G6PDH are the enzymes closely related to plant stress resistance and anti-aging ability, and the levels of their activity continuously rise as plants grow. The higher the activity of these three enzymes is, the stronger the stress resistance is at the same growth stage.

The assimilation of nitrogen (N) is an important physiological process in plant growth and development. Only assimilated into glutamic acid, glutamine and other organic N, inorganic N can be absorbed and utilized by plants, and GS is the key enzyme in ammonia assimilation [21]. Therefore, the higher the activity of GS is, the stronger the ability of N assimilation is, and consequently the greater the potential for increasing production is at the same growth stage. And GDH (glutamate dehydrogenase), widely found in plant bodies, is not a major member of N absorption, but it plays an important part in N metabolism in plants. GDH mainly exists in mitochondria and conducts ammonium assimilation in the aging process of plants or in such adverse circumstances as high temperature and moisture stress [22]. However it can go through oxidative deamination in the dark or under the conditions of carbon stress as to provide carbon skeleton to Krebs cycle [23] [24]. The activity level of GDH is closely related to the stable and high-yield characteristics of plants.

Previously, some millet researchers conducted a number of formation mechanism researches on some characteristics of varieties bred [25]-[28], but these studies were all carried out from perspectives of phenotype, plant growth and development processes, dry matter accumulation dynamic and so on. To date, researches on physiological mechanism of foxtail millet's stable and high yield on the basis of enzyme activity and nutrient absorption and transformation have seldom been reported.

The present study discussed the new variety of breeding method while introducing the Jigu32 breeding process, and revealed Jigu32's stable and high-yield physiological mechanism by measuring the activity of POD, SOD, G6PDH related to the resistance, the ability of absorbing and transforming N, phosphorus (P), potassium (K) and the activity of GS, GDH, and therefore provided references for the future breeding of stable and high-yield millet varieties.

2. Materials and Methods

Based on 1874 germplasms collected from different kinds of ecological areas in China, and after strictly identified in Shijiazhuang, the Target Character Gene Banks were constructed, including 42 high yield ones, 33 superior quality ones, 36 stress-resistant ones (resistant to rust, *Rhizoctonia solani* and drought), and 43 oversea ones. Using these resources and taking advantage of the accumulative effect of gene, we obtained a batch of new germplasms. After cross-breeding F98307, the new germplasms from the high yield gene bank, with Y97132, from the superior quality gene bank, we got seeds of F1. Subsequently, the seeds were hybridized with W98323 from the overseas gene bank and KB97156 from the stress resistance gene bank, using the ladder crossing method. After continuous directive breeding, we developed a new variety 206,058 in 2007. The breeding work was conducted alternatively in Shijiazhuang, Hebei and Sanya, Hainan.

The new variety was tested in all yield comparative trials in 2008, the nationwide millet regional trials in 2009 and 2010, and the national millet field trials in 2010, for its yield quantity, adaptation and resistance.

The mechanism of stable and high yield qualities of Jigu32 was studied in 2011, by testing the activity of POD, SOD, G6PDH, GS and GDH and the intake capability of N, P, K during the seedling, heading, early-filling and late-filling stages of all the materials, including Jigu32, Jigu31, paternal plants of Zhangzagu3, Zhangzagu5 and Zhangzagu6.

3. Results

3.1. Breeding Process of Jigu32

3.1.1. Identification and Selection of Target Resources

A total of 1874 foxtail millet samples were collected from all breeding programs in North China summer millet regions, and the northwest and northeast spring millet regions. Series of identification and selection were conducted among these samples in Shijiazhuang, Hebei, and 42 high yield ones (F), 33 superior quality ones (Y), 36 stress-resistant ones (KB, mainly resistance to rust), and 43 overseas ones (W) were selected as basic germplasms of respective gene banks.

3.1.2. Construction of Target Character Gene Banks

Based on the identified and selected germplasms with target characteristics, four Target Character Gene Banks were formed, which were the high yield, the superior quality, the stress resistance and the oversea gene bank, using sterile lines as tools and after continuously crossing and integrating for generations. The first three banks are main innovative goals while the oversea gene bank is mainly used to modify the adaptation of oversee materials.

3.1.3. Innovation of New Materials F98307, Y97132, W98323, KB97156 with the Target Characteristics

Making full use of accumulation effects of genes, over yearly crossing and breeding in Hebei and Hainan, we got the new superior quality material Y97132 and the stress-resistant material KB97156 in 1997, and the new high yield material F98307 and the new adaptation material W98323 from the oversea gene bank in 1998.

3.1.4. Development of the Target Variety Jigu32

The characteristics of high yield, superior quality and stress resistance were gradually aggregated together by the ladder crossing method, and foreign germplasms were introduced. As a result, target-cultivar Jigu32 was bred. To improve stress resistance and stable performance of its offspring, new stress-resistant material KB97156 was introduced at the last step of the ladder crossing for expanding genetic share of stress germplasms in the offspring. First, by crossing F98307 with Y97132, we got the seeds of F1, which combined the characteristics of superior quality and high yield. Second, by ladder crossing F1 with W98323, we got the J1 which contained more genetic resources. At last, by the second ladder crossing J1 with KB97156, we got the J2 which integrated the characteristics of high yield, superior quality and stress resistance.

By continuous crossing and directional selecting in the pedigree method of breeding, the offspring was developed into the new variety 206058 in 2007 which was of stable, high yield and superior quality (**Figure 1**).

It ranked the first position in all yield comparative trials in 2008 with an average yield of 6349.05 kg/hm^2, 11.79% higher than Jigu19. After the tests in the nationwide millet regional trials in 2009-2010 and the national millet field trials in 2010, the National Millet Varieties Committee examined and approved the variety, Jigu32, in December 2010.

3.2. Characteristics of Jigu32

3.2.1. Stability of Yield and Strong Stress Resistance

In 2010, Jigu32 took part in the nationwide millet regional trials. In Wuan, Hebei, there was only 186 mm rainfall during its growing period, but the yield of Jigu32 was up to 5665.05 kg/hm^2, 8.16% higher than Jigu19, and got the first position in the trials. In the trial field of the Institute of Crop Science of Nation Academy of Agriculture Sciences, it endured continuous raining and damages caused by *Rhizoctonia solani* and *Pyricularia setariae* during its late growing period and showed strong stress resistance. With the yield of 4887.45 kg/hm^2, 19.13% higher than Jigu19, it got the third position among all the tested varieties. In the trial field of the Institute of Crop Science of Shandong Academy of Agriculture Sciences, it endured arid weather conditions after sowing, and suffered more raining days, lower temperature, very little sunlight, and prevalence of *Rhizoctonia solani* during its grouting stage, but the yield was 4747.50 kg/hm^2, 29.45% higher than Jigu19, and got the first position. At other stations under normal weather conditions, the average yield of Jigu32 was 5525.25 kg/hm^2. Although weather conditions were very different from one another among the trial places during the growing period in 2010, the yield variation coefficient of Jigu32 was only 8.7%. As shown above, Jigu32 had very notable stability of yield and strong stress resistance.

In Quyang, Hebei, since there was rarely rainfall during growing period, maize and other crops hardly produced any yields, and even ordinary millet varieties produced less than 3000.00 kg/hm^2. But due to its notable resistance to arid weather, the yield of Jigu32 was still up to 5019.00 kg/hm^2. In 2012, suffering from continuous raining, low temperature, and little sunlight during the late growing period in Quyang, Hebei, ordinary millet varieties produced about 3450.00 kg/hm^2. However, the yield of Jigu32 was as high as 5818.50 kg/hm^2, due to its remarkable resistance to low temperature and sunless weather.

The results of experimentation and demonstration indicated that Jigu32 had strong stress resistance and stable yield. Therefore the yield of Jigu32 was the highest among the tested varieties (**Table 1**).

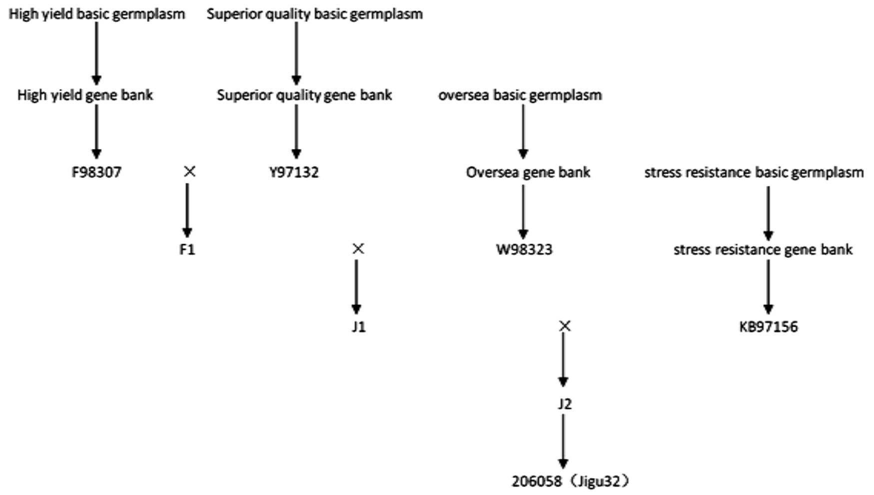

Figure 1. Breeding process of Jigu32.

Table 1. Yield of Jigu32 in 2010 national millet regional test.

Station	Climatic feature	Yield per unit (kg·hm^{-2})	Compare with contrast variety (±%)
Wuhan	Drougut	5665.05	8.16
Beijing	Rainy in late grough	4887.45	19.13
Jinan	Drougut in prophase and rainy in late	4747.50	29.45
Others	Normal	5525.25	8.11

3.2.2. Characteristics of High Yield

The average yield of Jigu32 was 6349.05 kg/hm^2 in the comparative trials of the Institute of Millet Crops, Hebei Academy of Agricultural and Forestry Sciences, in 2008, the highest among 18 varieties, and 11.79% higher than Jigu19. The average yield was 5133.30 kg/hm^2 in the regional trials in 2009-2010, the highest among all the tested varieties, and 9.42% higher than Jigu19. The average yields were 4811.85 kg/hm^2 in 2009 and 5454.60 kg/hm^2 in 2010, 8.05% and 10.67% higher than the control, respectively.

3.2.3. Superior Qualities

Calcium is very functional to human beings in such aspects as prevention from osteoporosis, myopia, hypertension, and simulation health growth of juveniles, so calcium-rich foods are very popular. According to the results from Zhengzhou Branch Center, the Cereal Analysis Center of the Ministry of Agriculture, there is 121 mg/kg calcium in Jigu32. Meanwhile, the qualities of flavor, commodity and nutrition are superior. As a result, Jigu32 was rated as the national secondary superior quality foxtail millet at the 9th High-Quality Millet Crop Identification & Appraisal Conference held by the Committee of Millet Crop, the Crop Science Society of China, in 2012.

3.2.4. Improvement of Comprehensive Performance

It is very convenient for Jigu32 to utilize resources of heat and light and then produce more dry-matter for its suitable growth period of 89d and its plant height of 119.43 cm. Even at the stage of maturation, the plants are still green and healthy. So the agronomic performance is significantly improved.

A fusiform spike is 19.56 cm long, properly tight. A single spike weighs 18.13 g, and the grains of a single one weigh 15.05 g. Grains are yellow, and 1000 grain weight is 2.73 g. The earing rate is as high as 94.5% - 96% in case of 600,000 - 675,000 seedlings/hm^2. Jigu32 has high bearing rate as well, as its millet percentage is 83.32% while its milled millet percentage is 75.85%. Therefore, the economic coefficient is significantly increased.

Furthermore, Jigu32 has green leaves at maturation, good maturity, and excellent comprehensive characteristics.

3.3. Physiological Mechanism of the Stable and High Yield of Jigu32

Based on the activities of POD, SOD, G6PDH, GS, GDH and the intake capabilities of N, P, K of Jigu32, this study showed that the stable and high yield mechanism of Jigu32 was as the followings.

3.4. Physiological Mechanism of the Stable Yield of Jigu32

3.4.1. As Plants Grow and Age, POD Becomes More Active, Which Makes Jigu32 More Resistant to Stress

The assay of POD activity of Jigu32 at different growing stages showed that: POD activity of Jigu32 was much higher than that of other tested varieties (**Figure 2**); as plants grew and aged, POD becomes more active (**Table 2**) at different growing stage. POD activity normally increased 0.62 times from the seedling to the heading stage, but from the heading to the filling stage under bad weather conditions such as hot, damp and sunless, the enzyme activity rapidly increased 4.99 times. Furthermore, during the filling period when the weather became arid and the plants aged, the activity still increased 0.61 times. That is, in its whole growing period, Jigu32 can sufficiently withstand hot, damp, sunless, arid and aging conditions, and this is one of the important mechanisms of its production stability.

3.4.2. As the Plants Grew and Aged, SOD Became More Active, Which Made Jigu32 Be Able to with Stand Aging

The assay of Jigu32 at different growing stages showed that: at the seedling, heading, early filling and late fill

Table 2. POD activities during the different growth stages (the ratio of the later growth stage and the previous one).

Varieties	Heading stage/Seedling stage	Initial of grouting/Heading stage	End of grouting/Initial of grouting stage
Male parent of Zhangzagu3	1.90	4.52	1.28
Male parent of Zhangzagu5	1.14	5.32	1.31
Male parent of Zhangzagu6	1.24	4.44	1.19
Jigu31	1.19	2.67	1.58
Jigu32	1.62	5.99	1.61

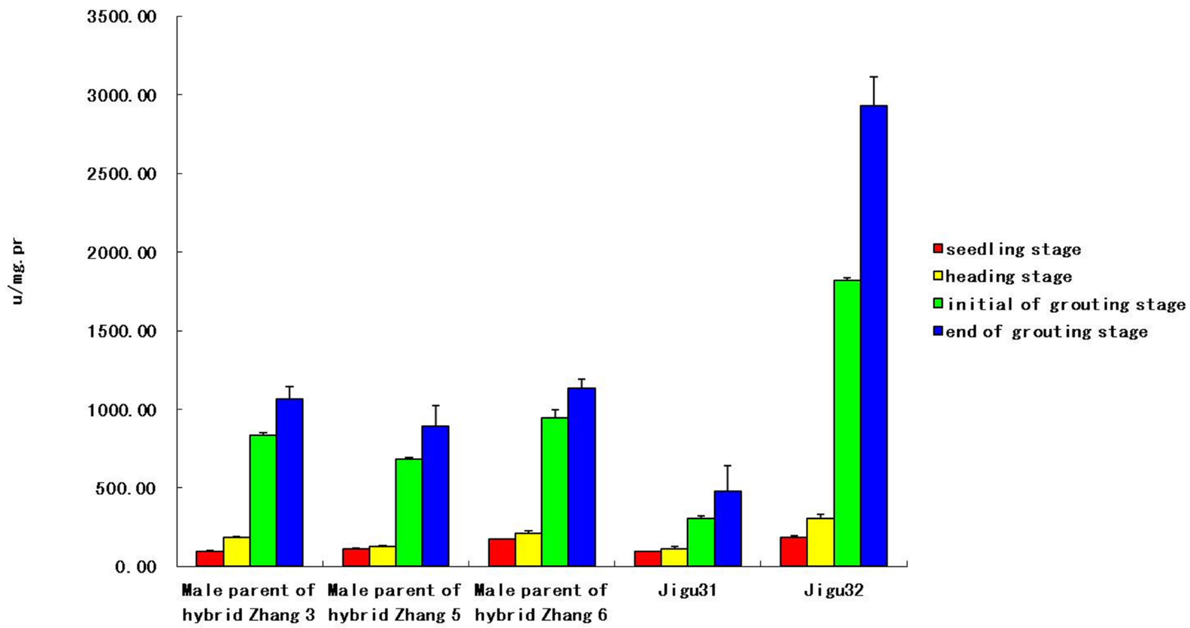

Figure 2. The dynamic changes of POD activity of Jigu32 and other tested varieties at different growing stages.

ing stages, the activities of SOD was 20.67 u/mg·pr, 22.83 u/mg·pr, 24.96 u/mg·pr and 32.82 u/mg·pr respectively (**Figure 3**). That meant the plants grew more actively at the early stage, and the green issue functioned longer and more effectively at the late filling stage. And that is the important physiological mechanism of Jigu32's resistance to premature senility and aging.

3.4.3. The Higher G6PDH Activity at Different Growing Stages Is the Third Important Physiological Basis of Stable Yield and Stress Resistance of Jigu32

The assay result of Jigu32 at different growing stages showed that: at the seedling, heading, early filling and late filling stages, the activity of G6PDH was 0.409ΔA/mg·pr·min, 0.504ΔA/mg·pr·min, 0.415ΔA/mg·pr·min and 0.293ΔA/mg·pr·min respectively. Jigu32 showed the highest G6PDH activity at different growing stages except at the heading stage; Jigu32 was slightly lower than male parent of Zhangzagu 5 in G6PDH activity at the heading stage, which led Jigu32 to the second place among the tested materials (**Figure 4**). This indicated that Jigu32 had less programmed cell death, stronger stress resistant and anti-aging ability. Therefore, a higher level G6PDH activity at different growing stages is an important physiological basis of stable yield and stress resistance of Jigu32.

3.5. Physiological Mechanism of the High Yield of Jigu32

3.5.1. More Efficiency of the Intake and Utilization of N, P, K Is the Major Physiological Mechanism of Its High Yield Ability

As **Table 3** shows, at the seedling stage, the contents of N, P, K in the leaves and stems of Jigu32 are highest among all tested varieties, 3.89% in leaves and 3.22% in stems; at the heading stage, the contents of N, P, K in the leaves and stems are still higher than the others, with 2.16% in the stems, though the contents in the leaves are 3.71%, comparatively high; at the early filling stage, the contents of N, P, K in the spikes are 2.66%, comparatively high, in the second place of all varieties, but the contents in the leaves and stems are still the highest, 3.32% and 1.26% respectively, and consequently the total contents are the highest; at the late filling stage, the contents of N, P, K in the leaves and stems are higher than the other varieties, secondly high in the spikes, but the total contents are the highest among all tested varieties. That means the high yield mechanism is mainly the strong, efficient capability of absorbing and utilizing nutrients (**Figure 5**). The content of P in Jigu32 is the highest in different organs at different growing stages, though it ranks the second in the leaves in the seedling stage (**Figure 6**). And the content of K in Jigu32 is the highest in different organs at different growing stages,

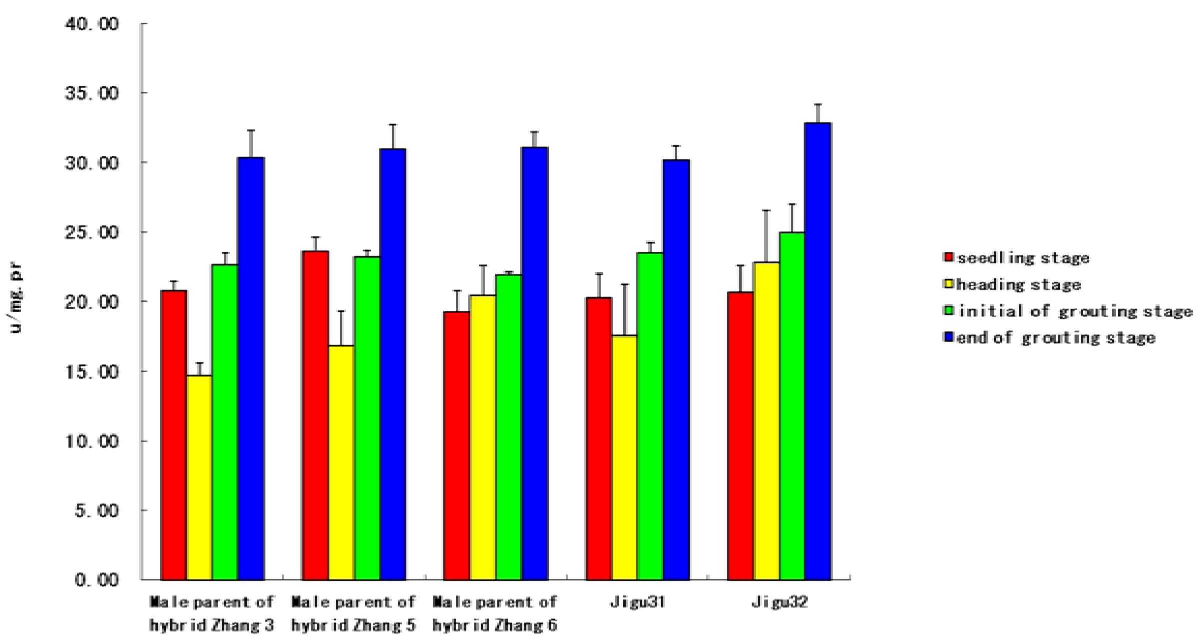

Figure 3. The dynamic changes of SOD activity of Jigu32 and other tested varieties at different growing stages.

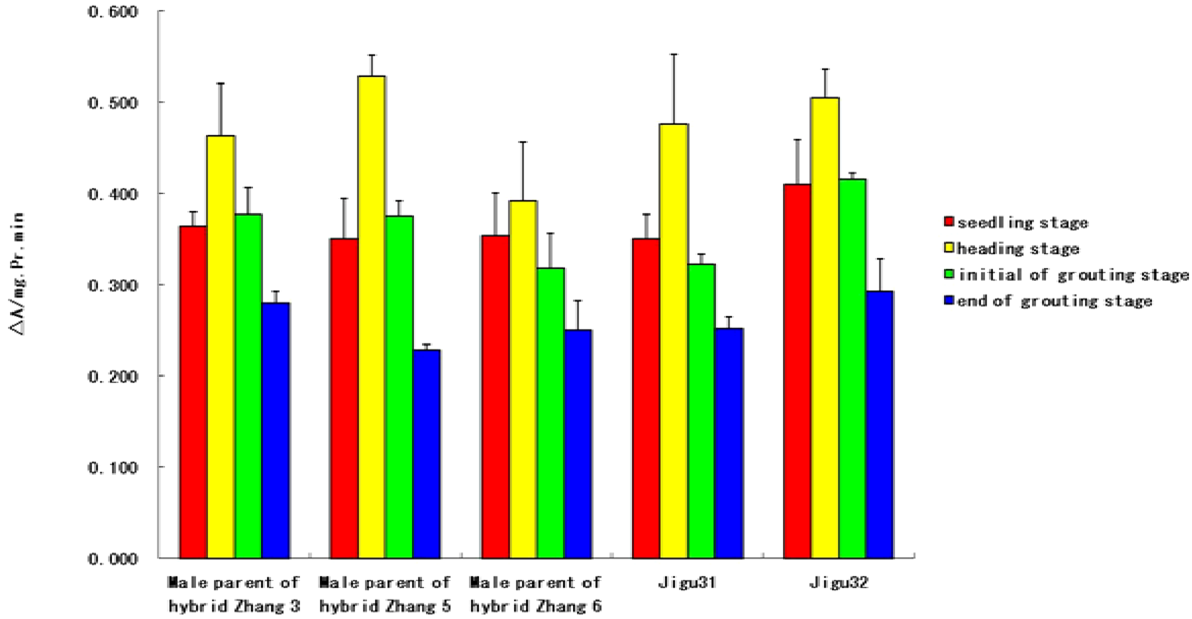

Figure 4. The dynamic changes of G6PDH activity of Jigu32 and other tested varieties at different growing stages.

Table 3. Absorption and transformation ability of N, P, K in different growth periods of Jigu32 and other cultivars.

Organ	Nutrients	Total N (%)				Total P_2O_5 (%)				Total K_2O (%)			
	Growth stage	Seedling stage	Heading stage	Initial grouting stage	Final grouting stage	Seedling stage	Heading stage	Initial grouting stage	Final grouting stage	Seedling stage	Heading stage	Initial grouting stage	Final grouting stage
Leaf	Male parent of Zhangzagu3	3.86	3.85	3.19	2.54	0.87	0.77	0.71	0.48	3.31	2.89	3.02	3.00
	Male parent of Zhangzagu5	3.88	3.75	3.17	2.34	0.84	0.71	0.72	0.42	3.22	3.36	3.00	2.17
	Male parent of Zhangzagu6	3.73	3.38	2.84	2.24	0.88	0.70	0.71	0.40	3.30	2.66	2.82	2.40
	Jigu31	3.53	3.47	2.74	2.38	0.79	0.82	0.72	0.59	4.31	3.90	3.60	2.78
	Jigu32	3.89	3.71	3.32	2.44	0.85	0.85	0.75	0.61	4.27	3.44	3.87	3.30
Stem	Male parent of Zhangzagu3	3.15	1.75	0.84	0.84	0.83	0.49	0.41	0.14	6.51	4.63	4.16	4.16
	Male parent of Zhangzagu5	2.84	1.82	0.75	0.75	0.70	0.45	0.39	0.14	5.99	5.74	5.17	5.17
	Male parent of Zhangzagu6	3.04	1.70	1.21	1.21	0.74	0.49	0.47	0.19	6.37	4.58	4.14	4.14
	Jigu31	3.00	2.44	1.20	1.20	0.78	0.74	0.34	0.35	6.57	6.32	4.31	4.31
	Jigu32	3.22	2.12	1.06	1.06	0.84	0.64	0.39	0.22	6.36	5.61	4.45	4.45
Spike	Male parent of Zhangzagu3			2.57	1.94			1.23	0.90			2.13	1.69
	Male parent of Zhangzagu5			2.69	2.04			1.26	0.91			2.05	1.21
	Male parent of Zhangzagu6			2.62	1.94			1.31	0.96			1.89	1.57
	Jigu31			2.74	1.65			1.37	0.84			2.58	1.22
	Jigu32			2.66	1.92			1.21	0.89			2.18	1.21

though it ranks the second in the stems in the seedling stage (**Figure 7**). All the analysis shows that Jigu32 has strong ability to convert nutrients from vegetative organs to reproductive organs into production as well as strong ability to absorb them, thus to lay a firm physiological basis for the high yield of Jigu32.

3.5.2. The Higher Activities of GS, GDH in All Organs at All Growing Stages Are the Important Physiological Basis for Jigu32 to Absorb and Convert Such Nutrients as N Efficiently

The assay result of Jigu32 showed that: at the seedling, heading, early filling stages, the activity of GS was on the highest level, 0.62△A540/mg·pr·min. 0.348△A540/mg·pr·min. 0.419△A540/mg·pr·min respectively; at the late filling stage, the activity of GS was 0.504△A540/mg·pr·min, which was the lowest among the tested materials (**Figure 8**). The activity of GDH was the highest at different growing stages (**Figure 9**). This explained that Jigu32 had strong N assimilation ability at the early growing stage, which laid a foundation for a high yield at the late stage; and the lower activity of GS at the late stage was caused by previous full filling and not striving for later maturation and, furthermore, the higher activity of GDH would make up the effect caused by the lower activity of GS.

4. Discussion

4.1. Significance of the Achievement of Jigu32

Jigu32 integrated the most important characteristics of its breeding targets, that is, stable production, high yield and superior qualities. Especially the yield stability would dramatically change severe fluctuations and losses of production, which makes possible bumper harvests in good years and stable production in bad years, and makes the millet industry develop more stably, smoothly and healthily.

4.2. Application of the Target Character Gene Banks Method to Breeding New Foxtail Millet Varieties with Stress Resistance, Stable and High Yield and Superior Qualities

Jigu32 is a result of the Target Character Gene Banks method. This method can sufficiently exploit the accumulation effects of genes to carry out transgression breeding, and successfully create transgressive variations. Furthermore, by employing hybridization, ladder crossing and the gene interaction, recombination, mutation, the

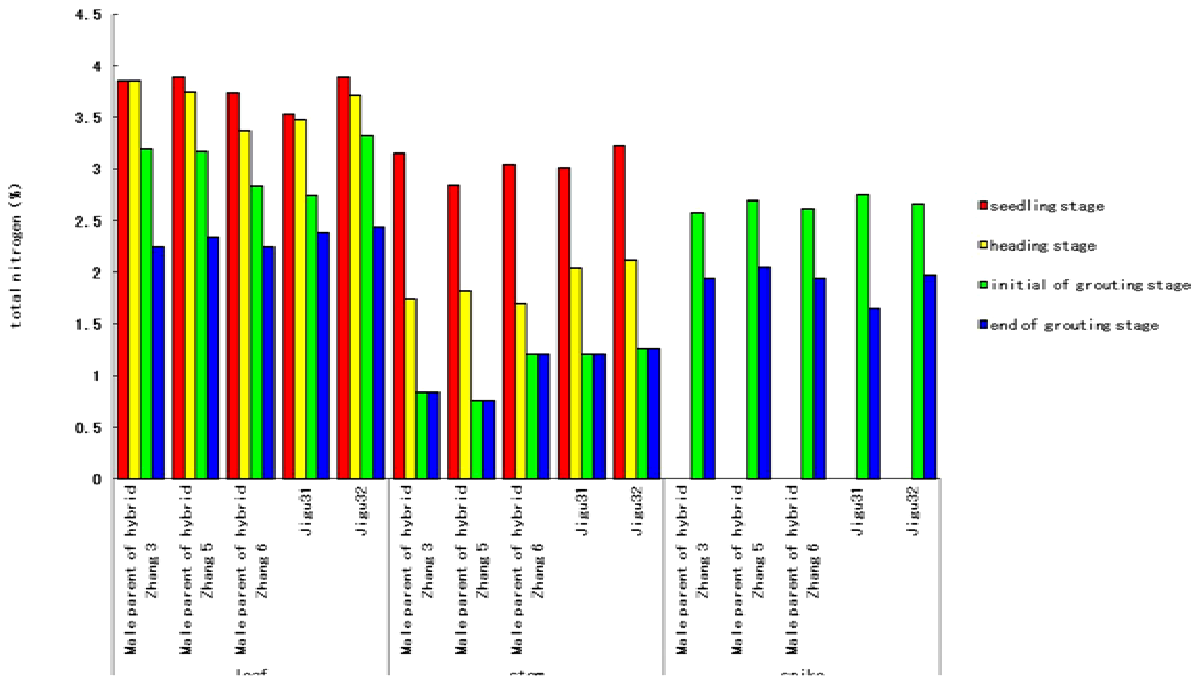

Figure 5. The dynamic changes of total nitrogen of Jigu32 and other tested varieties in different organs at different growing stages.

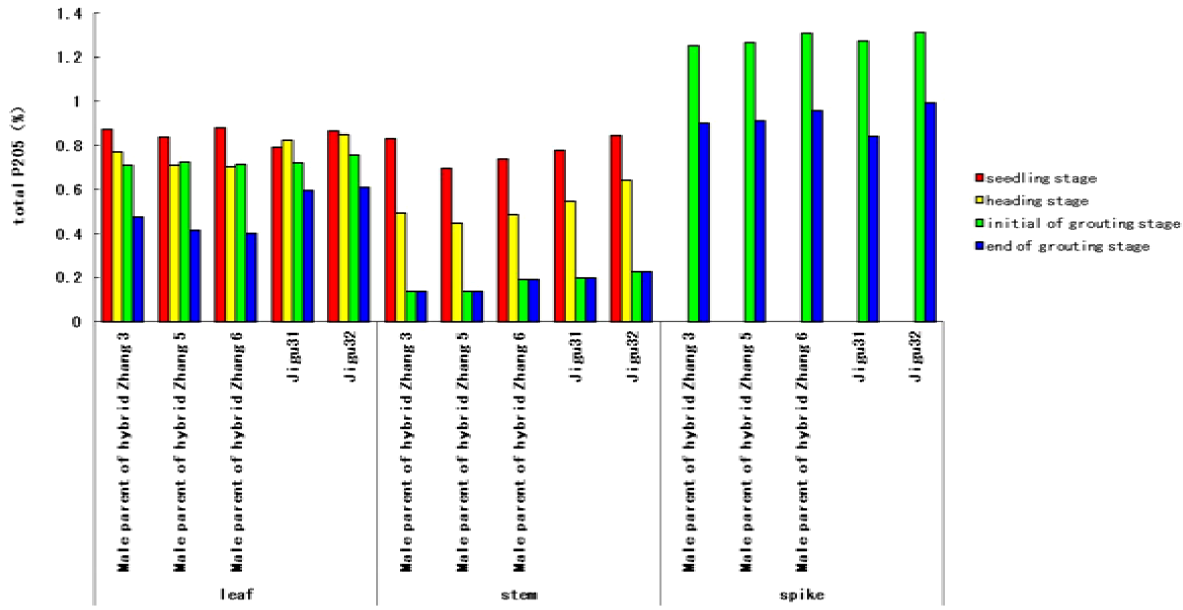

Figure 6. The dynamic changes of P_2O_5 of Jigu32 and other tested varieties in different organs at different growing stages.

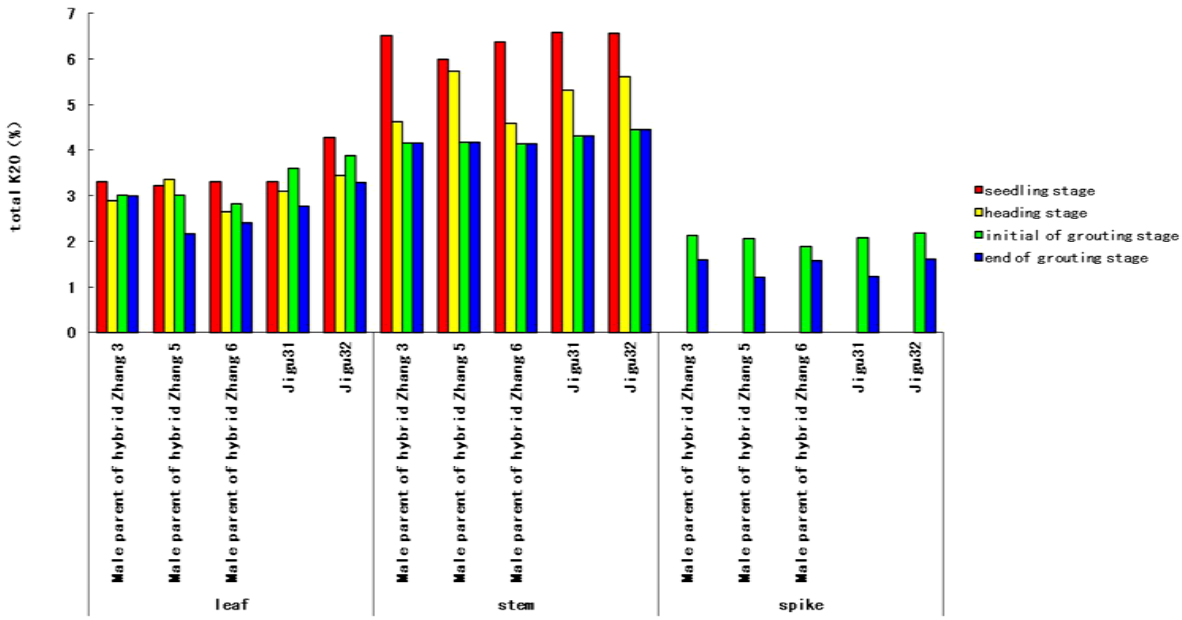

Figure 7. The dynamic changes of K_2O of Jigu32 and other tested varieties in different organs at different growing stages.

method can achieve ideal and superior varieties [29]-[31]. The desirable traits of the yield stability, superior quailties and high yield of Jigu32 are obtained and combined by using these different breeding ways, and thus it can be concluded that the method is very useful and effective.

4.3. Theoretical Significance of the Physiological Mechanism of the Characteristics of Jigu32

This research studies the physiological mechanism of Jigu32 and shows that the activity of POD, SOD and SOD and the capability of absorbing N, P, K are very important to yield, resistance to stress and aging at all growing stages. This offers theoretical support for future identification and breeding of new varieties.

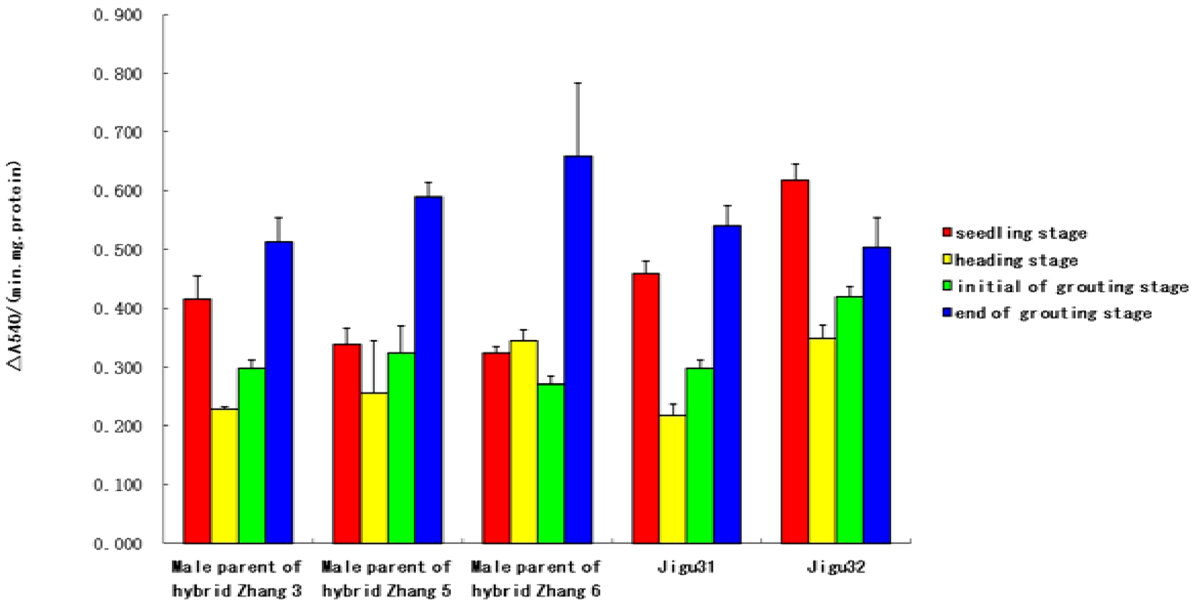

Figure 8. The dynamic changes of GS enzyme activity of Jigu32 and other tested varieties at different growing stages.

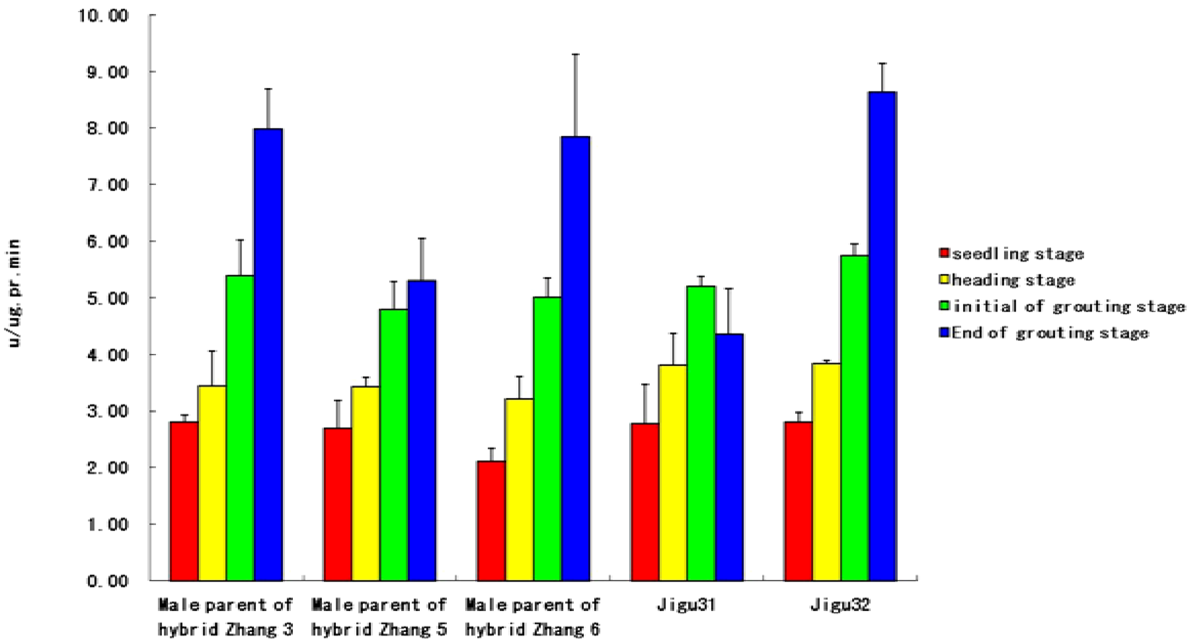

Figure 9. The dynamic changes of GDH enzyme activity of Jigu32 and other tested varieties at different growing stages.

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Abbreviations

POD, Peroxidase
SOD, Superoxide Dismutase
G6PDH, 6 Phosphate Dehydrogenase
GS, Glutamine Synthetase
GDH, Glutamate Dehydrogenase
N, Nitrogen
P, Phosphorus
K, Potassium