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Background: Improvement of crops' varietal traits not only involve the selection of superior varieties by research institutes or firms, but also depends on the adoption by farmers. In order to promote research institutes or seed firms developing superior new varieties, the Chinese government has established crop varietal approval system policies since early 1980s. Subsidies for growing superior crop seed varieties have been introduced since 2000s to stimulate farmers to employ superior seeds with improved traits in the production.

Results: Using data on nationally approved rice varieties and farmers' adopted varieties, this study examines rice varietal trait changes in China over the past four decades and explores the impact of national crop varietal approval policies on approved rice traits as well as the effect of seed subsidies on adopted rice trait changes. The results show that the yield of approved varieties and adopted varieties showed an upward trend over the past decades, but the volatility of approved varieties was significantly stronger than that of adopted varieties, and the yield of approved varieties was slightly higher than that of adopted varieties in most years. The rice quality of approved rice varieties showed a trend of continuous improvement, but the adopted varieties showed a downward trend. The disease resistance of the approved varieties failed to show an increasing trend overall, while the adopted varieties remained unchanged. National crop variety approval policies exert a significant positive impact on approved rice yield traits but exert a negative influence on disease resistance. Subsidies for superior seed varieties significantly increase adopted rice quality but decrease yield.

Conclusions: The results suggest that national crop variety approval policies are the gatekeeper of improved rice, so the government could improve the policies to more meet farmers' and finally consumers' needs. However, if the government were targeted at increasing rice yield through subsidies for superior seed varieties, it might not be helpful.

Keywords: Government policies, crop varietal traits, rice, approval and adoption, China

1. Introduction

The progress of science and technology is a main driving force of the growth of agricultural total factor productivity (Zhang et al. 2018), of which seed innovation contributes the most (Xin et al. 1995). Since the foundation of the People's Republic of China, improvement of adopted crop varietal traits has played a critical role in increasing crop productivity (Ma and Wu 2000; Wu et al. 1998a; Wu et al. 1998b). Studies show that during 1985-1994, the improvement of maize seed traits contributed 35.5% to maize yield (Wu et al. 1998a).

Establishment of a crop varietal approval system is a gatekeeper for crop variety improvement (Huang et al. 2005). The "*National Crop Variety Approval Trial Regulations"* promulgated in 1982 established national and provincial two-level crop variety approval systems. In 1989, the "*Regulations of the People's Republic of China on Seed Management*" established a crop variety approval system in the form of regulations. The "*Seed Law of the People's Republic of China*"[1] released in 2000 established a crop variety approval system in legal form for the first time. These laws and regulations lead the direction of crop production and variety improvement in China and have greatly promoted the rapid development of the seed industry. Moreover, the government has implemented a series of agricultural subsidy policies to encourage farmers to engage in grain planting and ensure stable and increased grain production. Subsidy for growing superior seed varieties is a special funding established by the central government to encourage farmers' adoption of superior crop varieties, improve the quality and yield of agricultural products, and mobilize farmers' enthusiasm for grain production in China. In 2002, the central government allocated 100 million yuan ($16.7 million) to subsidize the adoption of superior soybean varieties in Northeast China, which officially opened a precedent for agricultural subsidies. In 2004, the central government arranged special subsidy funding to support the adoption of superior rice varieties in 7 provinces of Hunan, Hubei, Jiangxi, Anhui, Heilongjiang, Jilin, and Liaoning to stimulate farmers in the main rice-producing areas to plant rice.

Rice is the most important staple food crop in China. Adoption of superior new varieties will not only increase its yield potential but also improve its quality and disease resistance. With the wide adoption of new varieties by farmers, China's rice yield has achieved

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[1] Hereinafter referred to as the "*Seed Law.*"

substantial growth (Figure 1). Based on the sources or types of new rice varieties, the adoption of rice varieties in China can be divided into four stages. Before the mid to late 1950s, it was often called the period of selection and identification of farm seeds. At that time, most of the adopted seeds were unapproved farmer seeds. From the mid-to-late 1950s to the late 1960s, the first dwarf rice variety was bred and adopted, and compared to original high-stalk lodging varieties, the yield of dwarf rice varieties increased by approximately 30%. The third stage was from the early 1970s to the mid-1980s, during which three-line hybrid rice breeding was approved. Its yield was 34.5% higher than that of dwarf rice (Yuan and Tang 1999). The fourth stage was from the end of the 1980s to the present. At this stage, the adoption of two-line hybrid rice was the third major breakthrough in the rice history of China, and rice yield increased by 111% compared to that in the 1950s.

Previous studies show that there is a disconnect between the adoption of agricultural technology and the needs of farmers in China, which leads to low efficiency in the adoption of new technologies by farmers and the transformation of scientific and technological achievements (Ling and Guo 1996; Gu and Zhang 1997). Research institutes and firms in China have approved a large number of superior new rice varieties for farmers. However, not all advanced technologies could be easily accepted and adopted by farmers due to a low level of relevant knowledge and information asymmetry (Huang et al. 1999). The gaps between approved and adopted new rice varieties in China are of great importance for the government to identify farmers' needs and promote the transformation of agricultural scientific and technological achievements into real agricultural productivity. Therefore, the objective of this study is to investigate trait changes and gaps between approved and adopted new rice varieties and examine the effect of national crop varietal approval policies on approved rice and subsidies for superior seed varieties on adopted rice trait changes.

There are two main contributions in this paper. First, this study employs national and provincial approval data and farmers' adoption data to investigate the trait changes of approved and adopted rice varieties and their differences over the past four decades, which could identify the gaps between seed supply and seed demand and provide empirical evidence for the government to implement appropriate seed policies. Second, previous studies mainly use survey data to explore the impact of superior seed subsidies on farmers' adoption behavior.

This study is based on provincial-level data to examine whether government policies significantly influence approved and adopted rice traits, which would be helpful for the government to adjust seed industry policy in the future. Although superior seed subsidies are now combined with direct subsidies for grain and comprehensive subsidies for agricultural materials in China, which are called agricultural support and protection subsidies, the results of this study are still meaningful to capture the influence of government policies on researchers' R&D behaviors.

2. Literature review

2.1 Rice variety approval system and changes in China

Crop varietal approval in China is that the *Varietal Approval Committee* conducts regional and production tests on newly bred varieties in accordance with prescribed procedures and comprehensively reviews the adoption value and suitable scope of the variety in terms of yield, growth period, quality, and resistance. It is a key process from the selection of a new crop variety to adoption (Yang et al. 2010), which is of great significance to the safety, stability and sustainable development of agricultural production.

Crop varietal approval in China can be traced back to the 1960s and 1970s. With the improvement of breeding technology and farmers' need to introduce new seeds, some provinces, such as Heilongjiang, Liaoning, and Guizhou, have successively carried out varietal trials, production tests, variety approval, registration or approval of rice and other crops. In 1982, the former Ministry of Agriculture, Animal Husbandry and Fisheries promulgated the "*National Trial Regulations on Crop Variety Approval*." Then, the National- and Provincial-level Crop Variety examination and approval Commissions were established. A series of regulations, such as the "*Regulations of the People's Republic of China on Seed Management*", "*Regulations on the National Crop Variety Approval*", and "*Measures for the National Crop Variety Approval*", were issued and implemented. The task of crop variety approval has gradually been standardized, and national and provincial two-level variety review systems have been established. The process has greatly promoted the selection and adoption of crop varieties in China (Ji et al. 2011). The "*Seed Law*" promulgated and implemented in 2000 clearly stipulated that five major crop varieties, including rice, maize, wheat, cotton and soybean, must pass national or provincial approval before being adopted.

Then, provincial governments formulated local seed laws and regulations. This implies that the varietal approval system of major crops such as rice has been legalized in China (Zhou and Jing 2006).

Since the establishment of national- and provincial-level systems for variety approval (SVA) in 1982, variety approval standards have varied among different periods, different provinces and different crops (Yang et al. 2010; Yang et al. 2014). Take national rice variety approval as an example. The first National Crop Variety Examination and Approval Committee (NCVEAC) formulated the following two approval standards for rice varieties from 1983 to 1988. First, the tested varieties in regional trials and production trials must increase their yields by more than 10% compared with the control varieties, or the yield growth must be statistically significant. Second, if the yield of the tested varieties is the same as that of the control varieties, at least one of the traits, such as quality, growth period, and resistance, must have outstanding performance (Yang et al. 2010).

From 1989 to 1996, the second NCVEAC revised rice varieties' approval standards. It emphasized that if national-level approved varieties were adopted across provinces, the reviewed variety must be through provincial approval in 2 provinces or has been approved in 1 province and performed outstandingly in national-level regional trials and production trials (Sun 1996).

From 1997 to 2001, the requirements proposed by the third NCVEAC emphasized further renewal of national-level approval varieties. The specific requirements are as follows. First, for the varieties that have been through two provincial-level approval processes, one of the approvals must be completed within two years. Second, clear requirements for yield, rice quality, and resistance levels of new varieties in national regional trials and production trials were proposed. Third, if trial varieties' resistance and rice quality were the same as the control one, its yield must increase 5% more than the control or an increase in yield is statistically significant; or if its resistance level is the same as the control group, major indicators of rice quality reach high-quality level 2 or above, and its yield can be less than 5% lower than the control; or if yield and rice quality are the same as the control, it can be resistant to at one major pest (Yang et al. 2010).

In 2002, the first National Crop Variety Approval Committee (NCVAC) was established by the former Ministry of Agriculture. Given the poor quality of rice varieties and high demand for high-quality rice from consumers, the first NCVAC adjusted the approval requirements of rice varieties during 2002-2006. In addition to not relaxing the examination and approval of high-yield and resistant varieties, for varieties with quality up to the grade 1, 2 and 3 national standards, the yield can be 15%, 10% and 5% less than that of the control. Under this standard, a large number of high-quality rice varieties emerged (National Crop Variety Approval Committee 2007).

After the establishment of the second National Crop Variety Approval Committee in 2007, the government further relaxed the yield requirements for high-quality rice varieties. For the rice varieties whose quality level reaches national standard of high-quality 1, 2, and 3 (or 1, 2, and 3 level better than the control), its yield index is relaxed to no more than 10%, 5%, 0% than the control. Moreover, a one-vote veto system is implemented for variety resistance, which requires that the comprehensive index of rice blast resistance be less than 7, while the highest panicle blast loss rate of the northern rice area and the Wuling mountainous area is less than 7 grades, and the highest panicle blast loss rate of the varieties in the southwestern rice region is not greater than 7 grades (Anonymous 2008).

In sum, the crop varietal approval system in China has experienced significant changes over the past decades. It potentially has a significant impact on the traits of newly bred rice varieties. One of the objectives of this study is to explore the effect of crop varietal approval policies on newly approved rice trait changes.

2.2 Subsidy policies for superior rice seed varieties in China

Seed subsidy for superior variety (SSV) is a special subsidy policy for improving the competitiveness of China's grain industry. Its main purpose is to encourage Chinese farmers to adopt new varieties or technologies in production and finally improve the quality and yield of grain (Zhang and Chen 2007). The subsidies are mainly for farmers (including farm employees) to use superior crop seeds in production.

The Chinese government started to organize and implement superior seed adoption subsidies in 2002, and the central government invested 100 million yuan ($ 15.4 million) to subsidize superior soybean seed varieties. In 2003, wheat was included in the scope of subsidies for superior seed varieties due to a sharp reduction in national grain production. In

March 2004, the Ministry of Finance and the former Ministry of Agriculture jointly formulated the "Interim Measures for the Management of Funds for the Promotion of Improved Varieties of Crops", which aimed to strengthen the management and supervision of the use of project funds. In April 2004, the "Interim Measures for the Management of Subsidy Funds for the Use of Improved Rice Varieties" was promulgated and implemented. The central government arranged special subsidy funds to support the adoption of superior rice seed varieties in 7 provinces, including Hunan, Hubei, Jiangxi, Anhui, Heilongjiang, Jilin, and Liaoning. The subsidy standard is 150 yuan/hm^2 for early rice, 225 yuan/hm^2 for medium rice and japonica rice, and 105 yuan/hm^2 for late rice. The subsidy area was often based on the actual planting area. In 2007, Sichuan, Guangxi and Chongqing were incorporated as provinces subsidizing superior rice seed varieties. In 2008, 29.33 million hectares of rice farmland in China implemented the full-coverage subsidy. At the same time, the subsidy standard for late rice was increased from 105 yuan//hm^2 to 225 yuan//hm^2, the subsidy for early rice was 150 yuan//hm^2, and the subsidy for medium rice, japonica rice and late rice was 225 yuan//hm^2.

A great number of studies have investigated the effect of superior seed subsidy policy on crop production but have obtained mixed results. Some scholars believe that superior seed subsidy policies are helpful for increasing grain yield (Zang et al. 2010; Wang and Xiao 2007; Zhang and Nie 2007; Qian and Zhao 2015), improving quality (Zhang and Nie 2007), decreasing prices (Zhang and Nie 2007), increasing sown area (Qian and Zhao 2015) and total factor productivity (Zhu et al. 2015), and encouraging farmers to engage in grain planting (Zang et al. 2010). Moreover, subsidy policy was helpful for improving farmers' technical efficiency (Li et al. 2014), promoting the adoption of new crop varieties (Leng et al. 2012; Wang and Wang 2008), and narrowing gender differences in variety adoption behavior (Fisher and Kandiwa 2014). There are also some scholars that argued that superior seed subsidy policy did not exert any significant impact on farmers' production. Guan (2014), for example, analyzed the production efficiency of major cotton-producing provinces in China before and after the implementation of cotton seed subsidies. The results showed that China's current cotton seed subsidy policy had a limited effect on improving cotton production efficiency. This study aims to examine the role of subsidies for superior rice seed varieties in promoting rice production in China, particularly in the impact on rice variety trait changes.

2.3 Previous literature on crop variety selection and adoption

The purpose of China's variety approval system is to encourage seed-breeding units to create new germplasm and breed new varieties. Therefore, relaxing or strengthening crop varieties' approval standards will significantly influence the R&D behavior of researchers from the public or private sector, especially firms and individuals. This will further influence the traits of new crop varieties developed by researchers. However, until now, there have been few studies examining the impact of seed industry regulations and policies on approved crop variety traits in China.

Previous studies have shown that the yield potential, quality and disease resistance of rice varieties that had been obtained through national or provincial approval systems have been improving, but different regions present different trends. Zhao et al. (1997), for example, analyzed rice regional trials for provincial-level approval in Zhejiang Province from 1991 to 1996 and found that the growth rate of rice yield remained at approximately 5% in general. Que et al. (2010), based on the data of approval rice varieties in Jiangsu Province from 1986 to 2005, indicated that rice's yield potential, quality and single resistance had improved, although its comprehensive resistance level had declined. Based on approval rice variety data in Sichuan Province from 1984 to 2014, Deng (2016) found that rice quality and resistance had been improved. Based on the trait data of mid-indica late-maturing rice varieties approved in Sichuan Province from 2001 to 2010, Zeng et al. (2012) showed that the plant height, panicle length, grain number and thousand-grain weight of rice had increased, but the growth period, effective panicle, seed setting rate and resistance grade of rice blast showed a downward trend.

The role of new variety adoption could often increase crop yield, improve agricultural product quality, adjust agricultural structure and strengthen disease resistance (Hu 1998). Decision-making for new variety adoption has been extensively examined by many scholars. The research focuses on two aspects: the role of new variety adoption and determinants of farmers' decisions on adopting new varieties. Studies have shown that the adoption of new varieties increases crop yields (Shiyani et al. 2002; Manda et al. 2020; Ali and Abdulai 2010), farmers' incomes (Ali and Abdulai 2010; Manda et al. 2020; Shiyani et al. 2002; Demont and

Tollens 2004; Mendola 2007; Verkaart et al. 2017; Clark et al. 2017) and consumer expenditures (Alene et al. 2015) and reduces poverty (Alene et al. 2015; Verkaart et al. 2017) and pesticide use (Ali and Abdulai 2010).

The main factors that influence crop new variety adoption are farmland scale (Shiyani et al. 2002), policy reforms (Sánchez-Toledano et al. 2018), cost and output of new varieties (Shiyani et al. 2002; Herath et al. 1982; Barkley and Porter 1996; Asrat et al. 2010) and information (Matuschke and Qaim 2009; Shiferaw et al. 2015). Based on corn adoption data from farmers in Minnesota and Wisconsin in the United States, for example, Useche et al. (2010) found that farmers' preference for variety traits was influenced by producer and regional heterogeneity. Negatu et al. (1999) employed data from 96 wheat farms in Ethiopia and found that farmers' decision to adopt new varieties was affected by factors such as farm size, farmer income, and soil type. Mariano et al. (2012) found that farmers' adoption of new varieties in rice production in the Philippines was affected by factors such as ownership of machinery and irrigation water supply. Using survey data from 200 corn farmers in Mexico, Sanchez et al. (2018) found that the 1994 North American Free Trade Agreement Mexico's agricultural policy reform had a significant impact on the adoption rate of superior seeds.

In recent years, some scholars have also examined major factors affecting Chinese farmers' decision to adopt new varieties, which were mainly divided into economic factors and noneconomic factors. Economic factors mainly include farmers' income level (Qi et al. 2012; Zhu and Zhao 1995; Meng et al. 2005; Huang et al. 2012) and seed prices (Li et al. 2018; Li 2010; Meng et al. 2005), while noneconomic factors mainly include mechanical input (Chang and Yao 2005), factor endowments (Chang and Yao 2005), and policy rewards (Li 2010; Meng et al. 2005; Zhu and Zhao 1995). Zhu et al. (1995) conducted a survey of 289 farmers in impoverished mountainous areas in western Hubei and found that government subsidies promoted farmers' adoption of new technologies. Based on survey data of 196 farmer households in 4 provinces, Song et al. (1998) found that farmers' decision-making regarding new variety selection was affected by farmers' income level, arable land area, and education level. In addition, some studies have shown that the maximum adoption area of superior rice varieties is mainly influenced by yield potential, quality and disease resistance (Shi et al. 2008). Based on the potential impact of superior seed subsidies on farmers' choice of rice seeds, this study aims to investigate whether subsidies for growing superior seeds promote farmers to choose high-yield, high-quality and high-resistance-to-pest rice varieties.

3. Methodology

3.1 Data

This study employs four sets of sources of data. Data set 1 involves major agronomic traits of approved rice varieties, such as yield, growth period, plant height, rice quality indicators, resistance to major diseases and insect pests. The information is mainly from the regional experiments on seed varieties published by the Ministry of Agriculture, the "*National Crop Approved Varieties*" and "*Chinese Rice Varieties and Their Genealogy*" published by *China Agriculture Press* over years, and the website of the National Rice Data Center.

Data set 2 involves major agronomic traits and planting areas of adopted rice varieties, which are mainly those whose planting areas are more than 6666.7 hectares in at least one province in a certain year. It is from the "*Statistical Table for the adoption of National Major Crop Varieties*" and the "*Chinese Rice Varieties History.*"

Data set 3 includes the data regarding economic factors that influence rice adoption, such as per capita disposable income and per capita arable land area. These data are from the National Bureau of Statistics, the "*China Statistical Yearbook*", and the "*China Rural Statistical Yearbook.*"

Data set 4 includes data on agricultural input factors that may also affect farmers' decisions regarding rice variety adoption, such as the total power of agricultural machinery, flood disaster areas, drought disaster areas, and diseases and insect or pest areas. These data are from the National Bureau of Statistics, the "*China Agricultural Statistical Yearbook*", and the "*Fifty Years of China's Plant Protection*".

3.2 Conceptual framework

Breeding superior crop varieties is an effective measure to promote the progress of agricultural technology, while adopting new varieties in production and their performance are the standards to measure a country's agricultural breeding technology (Hu 1998). This study attempts to investigate the trait changes of approved and adopted rice varieties from the perspectives of supply and demand.

In terms of the supply of new rice varieties, researchers in the public sector aim to select seed varieties that are likely to meet the country’s national development strategy, while firms give top priority to developing varieties that satisfy farmers’ needs and finally make more profits (Jin et al. 2010). However, even though researchers have developed a new variety, it does not mean that it could be a good variety in production. Since the difference in appearance characteristics among different varieties of the same crop is small, it is very difficult for farmers or consumers to distinguish the difference in its traits and quality. This suggests that the anti-counterfeiting of seed commodities is poor, which has a great impact and a strong negative multiplier effect on production. Once fake and inferior seeds flow into the market, they will cause great losses to agriculture and form various "seed accidents". Therefore, one of the major purposes of a country’s approved system for seed innovation is to choose superior seed varieties to avoid "seed accidents." Accordingly, requirements of approval systems will influence researchers’ R&D behavior and the products they develop. This study, on the one hand, aims to examine trait changes in newly bred rice varieties developed by research institutes or firms during the past four decades and the impact of crop variety approval standards.

From the standpoint of demand, previous studies show that farmers’ decisions on rice variety adoption are often influenced by varieties’ traits (Shi et al. 2008). In other words, varieties adopted by farmers to some extent indicate what kind of new varieties are needed in real production. If subsidies for growing superior seed varieties could encourage more farmers to choose seeds with better traits, such as high quality or resistance to disease, rice aggregate traits would change accordingly under the influence of subsidies. This study, on the other hand, attempts to investigate newly bred rice varieties’ trait changes adopted by farmers during the past four decades and the impact of subsidies for superior rice seed varieties.

Moreover, with the improvement of people’s living standards and enhancement of other agricultural technologies, researchers will also adjust the traits of newly developed seed varieties. For example, with the improvement of fertilizer technology and increasing use of fertilizer, the yield potential of high stem rice varieties is limited due to their nonlodging resistance. Low stem and lodging resistance to high yield have become a new goal for breeders in the 1950s in China (Hu 1998). Similarly, serious rice blast in Zhejiang Province occurred in 1975 and 1984. After that, most rice varieties used by farmers have strong blast resistance (Hu 1998). Therefore, per capita disposable income, per capita cultivated land area, mechanization and diseases as well as insect pests are expected to exert some influence on the trait changes of newly bred rice varieties. The specific theoretical framework is as Figure 2.

3.3 Model specification

3.3.1 Variety approval model

Since crop variety approval standards involve many requirements on crop variety traits, changes in the approval standards would result in approved crop trait changes. In this study, three major agronomic traits of rice, including yield-relevant traits (growth period, plant height and yield), rice quality and disease resistance, were employed. The head rice rate is used as rice quality, while the resistance of rice to blast and bacterial blight indicates rice disease resistance. It is worth noting that the trait value of approved rice varieties in this study was obtained by averaging all varieties' traits in specific provinces[2]. Provincial-level varieties are calculated by directly averaging approved varieties. For national-level approved varieties, the first step is to adjust the approved province from "national" to 31 provinces and then average all the varieties in a specific province.

The specific model is as follows:

$$\begin{aligned}\ln Y_{it} &= \beta_0 + \beta_1 Seedlaw + \beta_2 STDdum + \beta_3 \ln DPI_{it} + \beta_4 \ln Rjgdarea_{it} \\ &+ \beta_5 \ln Machine_{it} + \beta_6 Dry_{it} + \beta_7 Flood_{it} + \beta_8 Pest_{it} + \beta_9 Hybrid_{it} \\ &+ \beta_{10} Middle_{it} + \beta_{11} Latter_{it} + \beta_{12} Indica_{it} + \alpha_i + \mu_{it} \end{aligned} \tag{1}$$

where LnY_{it} includes $LnYieldmu_{it}$, $LnDuration_{it}$, $LnHeight_{it}$, $lnHeadrice_{it}$ and $LnBacterbt_{it}$. $LnYieldmu_{it}$ is the variety's trial (regional trial or production trial) yield in logarithm, $LnDuration_{it}$ is the approved rice's period of duration[3] in logarithm, $LnHeight_{it}$ is the plant height[4] in logarithm, $lnHeadrice_{it}$ is the percentage of head rice

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[2] For approved rice varieties, agronomic traits (AT) of a certain province in a certain year can be represented by the simple average value of agronomic traits of all rice varieties approved in that year in that province. It is as follow: $MAT_{it} = \frac{1}{N_{it}} \sum_{k=1}^{N_{it}} AT_{kit}$

where i represents the province, t represents the year; MAT_{it} represents the simple average traits of all approved rice varieties in province I in year t; k=1, 2..., Nit; N_{it} represents the total number of approved varieties in province i in year t; AT_{kit} represents agronomic traits of the approved variety k in province I in year t.

[3] Period of duration refers to the time that a crop elapses from seeding to seed maturity (harvesting).

[4] Plant height refers to the distance between the base of the plant and the top of the main stem.

to net rice sample mass in logarithm, and $LnBacterbt_{it}$ is the level of disease resistance (bacterial blight and rice blast) in logarithm. The variable *Seedlaw* represents a dummy variable before or after 2001 when the Chinese government issued the first seed law in China. It equals 1 in or after 2001, otherwise 0. The variable $STDdum$ represents a set of dummy variables of the variety approval standard. The crop variety approval reforms are divided into five stages. The first stage is 1982-1988, the second stage is 1989-1996, the third stage is 1997-2001, the fourth stage is 2002-2006, and 2007 is the fifth stage. The first stage of 1982-1988 is taken as the baseline. *LnMachine*, *LnDPI*, and *LnRjdgarea* are the logarithms of the degree of mechanization, per capita disposable income, and per capita arable land area, respectively. The variables *Flood*, *Dry*, and *Pest* are a set of disaster variables that represent the proportion of flood disaster area, drought disaster area, disease and insect damage area to the sown area of crops, respectively. *Hybrid*, *Middle*, *Latter*, and *Indica* represent the proportions of hybrid rice, middle rice, late rice, and indica rice to the total number of approved varieties, respectively.

Fixed-effect model is used in the model estimation. It is worth noting that due to inconsistent statistical caliber of disease resistance, it is set to five levels: the lowest value 1 represents high resistance of the variety, 3 represents resistance, 5 represents medium resistance, 7 represents sense, and the highest value 9 represents high sense. Since this study simply averages the variety traits by province, the original five-level disease resistance becomes a continuous variable.

3.4 Variety adoption model

Consistent with the traits of the approved varieties, this study selected 6 agronomic traits of rice for regression analysis, including rice yield, growth period, plant height, quality and disease resistance. The traits of adopted rice varieties were obtained after weighing the average rice planting area by province. The specific formula is as follows:

$$WAT_{it} = \sum_{k=1}^{N_{it}} \frac{area_{kit}}{area_{it}} \bullet AT_{kit} \qquad (2)$$

where WAT_{it} represents the weighted average of the traits of all rice varieties used in province i in year t; k=1, 2..., N_{it}; N_{it} represents the number of adopted varieties (actually planted) in province i in year t; and AT_{kit} represents the agronomic traits of variety k adopted (actually planted) in province *i* in year *t*.

As mentioned above, this study assumes that subsidy policies for superior varieties will affect the traits of rice varieties adopted in China. To examine the contribution of subsidy policy to the changes in the traits of adopted rice varieties, this study employs the following model:

$$\begin{aligned} \ln Y_{it} &= \beta_0 + \beta_1 Allowance + \beta_2 Subsidy + \beta_3 \ln DPI_{it} + \beta_4 \ln Rjgdarea_{it} \\ &+ \beta_5 \ln Machine_{it} + \beta_6 Dry_{it} + \beta_7 Flood_{it} + \beta_8 Pest_{it} + \beta_9 Hybrid_{it} \\ &+ \beta_{10} Middlelatter_{it} + \beta_{11} Indica_{it} + \alpha_i + \mu_{it} \end{aligned} \quad (3)$$

where LnY_{it} includes $LnYieldmu_{it}$, $LnDuration_{it}$, $LnHeight_{it}$, $lnHeadrice_{it}$ and $LnBacterbt_{it}$. The variable *Allowance* represents a dummy variable of subsidy policy for improved rice varieties. It equals 1 for Hunan, Hubei, Jiangxi, Anhui, Heilongjiang, Jilin, Liaoning, 7 provinces from 2004 and for all provinces after 2010; otherwise, it equals 0. The *Subsidy* variable represents the direct subsidy policy for grains. It equals 1 since 2004 for all provinces, otherwise 0. Other control variables have the same definition as Eq. (1.2). Similarly, a fixed-effect model can be used to estimate Eq. (1.3). To avoid pseudo regression, this study also conducts a test of the stationarity of the data. The methods and results are provided in the supplementary materials.

4. Results

4.1 Trait changes of approved and adopted rice varieties

The results show that the traits of approved and adopted rice varieties present completely different trends in China. Regarding the yield, both approved and adopted varieties showed an upward trend. However, the fluctuation of the approved varieties was significantly stronger than that of adopted varieties, and the yield of approved varieties was slightly higher than that of adopted varieties in most years (Figure 3). The yield of approved rice varieties increased from 402.63 kg/mu in 1982 to 599.12 kg/mu in 2016, with an average annual growth rate of 1.14%, while the yield of adopted varieties increased from 445.33 kg/mu in 1982 to 554.97 kg/mu in 2016, with an average annual growth rate of 0.63%, which was lower than the average annual growth rate of approved varieties. This suggests that the increase in the yield of approved rice varieties has encouraged farmers to choose rice varieties with high yield potential, which is conducive to promoting the improvement in the yield of rice varieties used in China.

Plant height presented similar changes to the trait yield (Figure 4), which is also in line with the fact that yield and plant height were highly related. Breeding researchers and farmers tend to increase yield by increasing plant height. The plant height of approved varieties increased from 87.45 cm in 1982 to 110.89 cm in 2016, with an average annual growth rate of 0.68%, while the plant height of adopted varieties increased from 89.96 cm in 1982 to 108.17 cm in 2016, with an average annual growth rate of 0.53%.

For the growth period, approved varieties first decreased in the early 1980s and then increased in the 1990s, which is consistent with the goal of China's rice variety improvement. Early maturity breeding in the late 1970s shortened the average growth period of rice. With the changes in breeding goals, increase in labor costs, and rising demand for single-season rice and mid-season rice, the average growth period has gradually increased. Figure 5 shows that the growth period of approved varieties has increased and decreased significantly, and the annual growth rate has remained between -12.17% and 7.62%, while the adopted varieties have generally shown a relatively gentle growth trend.

The rice quality of approved rice varieties in China has been continuously improved to meet people's urgent needs for high-quality rice. This study uses the head rice rate to evaluate rice quality; that is, the higher the head rice rate is, the better the rice quality (Figure 6). The head rice rate of approved varieties has shown an upward trend in general. It increased from 50.5% in 1982 to 59.34% in 2016, but the fluctuation range was large, with an annual growth rate between -10.23% and 22.34%, which revealed that breeding research staff gradually regarded rice quality indicators as breeding targets. In contrast, the head rice rate of adopted varieties shows a downward trend, from 70.2% in 1982 to 60.05% in 2016, with an annual growth rate between -8.64% and 4.97%. The fluctuation range is smaller than that of the approved varieties. This shows that farmers always consider the issue of rice quality in rice production. In recent years, they may have relaxed their rice quality indicators after comprehensively considering yield and other influencing factors. However, the head rice rate has always remained above 55%.

Compared with economic traits, the trend of disease resistance traits was different

(Figure 7 and Figure 8). The bacterial blight resistance and rice blast resistance of the approved varieties fail to show an increasing trend in general, which may be related to the fact that breeding researchers do not regard disease resistance as a breeding goal. Bacterial blight resistance and rice blast resistance of the adopted varieties do not change much as the whole. In particular, it was concentrated at the levels of 5 and 7, which suggests that farmers always regard disease resistance as an important criterion in the selection of varieties. For bacterial blight resistance, the resistance grade of the approved varieties was always maintained between 4 and 9, with large fluctuations, and the average annual growth rate was maintained between -35.28% and 56.28%. The resistance grade of the adopted varieties remains between 6 and 7, and the fluctuation range is relatively gentle. For rice blast resistance, the resistance grade of the approved varieties is maintained between 2 and 9, with large fluctuations, and the average annual growth rate is between -52.36% and 119.3%. The adopted varieties are maintained between 4 and 7, showing a gentle upward trend, with an average annual growth rate of -12.63% to 12.16%.

4. 2 Estimation results of approved policies on approved rice variety traits

The estimation results of approved rice varieties' trait changes are shown in Table 1. The results show that approved rice varieties' yield, plant height and growth period in terms of yield traits increase by 1.4%, 0.5%, and 0.6%, while head rice rate decreases by 0.169% in terms of rice quality. From the perspective of resistance to disease, bacterial blight resistance decreases by 0.2% and rice blast resistance increases by 1.5% per year. This suggests that seed breeding technology has been increasing the yield of rice and improving its disease resistance as a whole.

Variety approval standards have a significant impact on the traits of approved rice varieties. The coefficients of head rice rate and bacterial blight resistance grade are significantly positive, while the coefficients of yield, plant height, growth period and rice blast resistance are significantly negative. This suggests that the head rice rate and bacterial blight resistance grade in the last four approval stages are generally higher than those in the first stage, while the rice yield is generally lower than that in the first stage. The plant heights of the third and fourth stages decrease by 2.4% and 3%, respectively, compared with the first stage, while the growth periods of the second, third and fifth stages are reduced by 3.4%, 2.1% and 6%, respectively, compared with the first stage. The results are in line with the requirements for varieties in different stages of approval standards. The first stage focuses on the yield of varieties and requires a 10% increase in yield, while the latter four stages relaxed the restrictions on the increase in yield, instead focusing on the quality and resistance of rice. Bacterial blight and rice blast resistance show opposite trends at different approval stages. This may be because bacterial blight can be effectively controlled with pesticides, and breeders may gradually no longer regard bacterial blight resistance as the main breeding goal.

The coefficients of *Seed Law* on growth period and head rice rate are significantly negative, the one on resistance grades of bacterial blight and rice blast are significantly positive, but on yield and plant height is not significant. Specifically, after the promulgation of the *Seed Law*, the growth period and head rice rate of the approved rice varieties decreased by 6.3% and 4.9%, and the resistance levels of bacterial blight and rice blast increased by 8.9% and 25.7%, respectively. There was no significant difference in rice yield or plant height before and after the promulgation of the *Seed Law*. This indicates that *Seed Law* has relatively little effect on trait improvement in Chinese rice-approved varieties and has failed to significantly improve rice yield potential, rice quality and disease resistance.

From the perspective of rice types, the coefficients of the ratio of hybrid rice on yield, plant height, growth period and bacterial blight resistance grade are significantly positive, which indicates that the higher the proportion of newly bred hybrid rice is, the higher the yield, plant height, growth period and white leaf blight. For every 1% increase in the proportion of hybrid rice, the yield, plant height, growth period and bacterial blight resistance grade will increase by 0.1%. The coefficients of the ratio of medium rice on yield, plant height, growth period and rice blast resistance are all positively significant. For every 1% increase in the proportion of late rice, the yield, head rice rate and rice blast resistance will increase by 0.1%, 0.036% and 0.1%, respectively. The coefficient of indica rice for bacterial blight grade is also significantly positive, and the coefficients for other explained variables are significantly negative. This implies that the higher the proportion of indica rice, the higher the bacterial blight resistance grade, while the lower the yield, plant height, growth period, head rice rate and rice blast resistance. The control variables also significantly influence some traits of approved varieties[5].

4.3 Estimation results of the impact of seed subsidies on adopted rice traits

The estimated results are shown in Table 2. In all adopted rice variety models, most of the coefficients of the time trend variables are significant, which shows that within the study time range (1982 to 2016), there are significant changes in the five agronomic traits. The annual growth rates of the adopted rice varieties' yield, plant height, growth period, bacterial blight resistance and rice blast resistance were 0.9%, 0.3%, 0.2%, 0.5% and 8.1%, respectively, while the annual decreasing rate of the head rice rate was 0.11%. Meanwhile, due to the lag in the adoption of new varieties by farmers, this study assumes that the farmers' decision to adopt new varieties in that year is affected by the economic and noneconomic factors of the previous year. Therefore, we consider the first-order lag period for the control variables of yield, plant height, growth period, head rice rate, bacterial blight and rice blast resistance.

The subsidy policy for improved varieties has a significantly positive coefficient for head rice rate, significantly negative coefficients for yield and rice blast resistance, and a nonsignificant coefficient for plant height, growth period and bacterial blight resistance grade. This implies that after the implementation of the subsidy policy for improved varieties, the head rice rate increases by 1.2% compared with before, while the yield is reduced by 4% and the resistance level of rice blast is 46.3% lower than that before the implementation of the subsidy policy. In other words, the resistance level of rice blast increases by 46.3%. This suggests that the subsidy policy for improved varieties is conducive to the improvement of the traits of farmer adopted rice varieties in China. Farmers take rice quality and disease resistance into account first when making decisions about new varieties instead of considering rice yield potential as the only decision variable.

The impact of the direct subsidy policy for planting grains on the adopted rice varieties has been shown to improve the quality of rice, but it fails to significantly increase the yield

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[5] Since it may take 5 to 8 years for a rice variety to be successfully bred, and it may take 3 to 5 years for a bred variety to pass the national or provincial approval, this study considers that the influence of economic and noneconomic factors in the control variables on the changes in traits of approved varieties may have a lag of 5 to 15 years. This study assume that per capita disposable income, per capita arable land, machinery, floods, droughts and pests have the same lag period. According to the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), the lag periods of the control variables for yield, plant height, growth period, head rice rate and bacterial blight are 11, 6, 11, 6 and 15 years, respectively (Details see Table S3).

potential and disease resistance.

Rice variety types also have significant effects on the traits of adopted rice varieties. For every 1% increase in the proportion of hybrid rice, the rice blast resistance grade will increase by 0.4%, and the head rice rate and bacterial blight resistance grade will decrease by 0.02% and 0.1%, respectively. For every 1% increase in the proportion of mid-late rice, plant height, growth period, head rice rate and rice blast resistance will increase by 0.2%, 0.1%, 0.1% and 2.9%, respectively, and bacterial blight resistance grade will decrease by 0.4%. The coefficients of the proportion of indica rice on plant height, growth period and head rice rate are all significantly negative.

5. Conclusion

This study employs data on national-level and provincial-level approved rice varieties and adopted rice varieties over the past four decades to investigate the trait changes and differences of approved and adopted rice varieties in China. It also analyzes the influence of variety approval standards on the traits of approved rice varieties and the influence of national subsidies for superior seed varieties on the traits of adopted rice varieties.

The results show that the yield, plant height, growth period and head rice rate traits of the approved and adopted varieties were significantly improved, while the bacterial blight and rice blast resistance increased in the 1980s but showed a downward trend after the 1990s.

Crop variety approval standards play an important leading role in the direction of rice variety breeding and significantly improve the rice quality and resistance of approved varieties. The improvement of variety approval standards is conducive to promoting the selection of rice varieties and guiding the direction of rice variety trait improvement.

To a certain extent, the subsidy policy for improved varieties has significantly improved the quality of the adopted varieties but has failed to effectively promote the improvement of traits such as yield, plant height and growth period. The head rice rate and rice blast resistance have increased by 1.2% and 46.3% compared with before the implementation of the policy, which shows that the subsidy policy is beneficial to the improvement of the traits of rice varieties in China. Therefore, improving the rice subsidy policy will help encourage farmers to adopt new varieties, increase farmers' willingness to grow grain, convert the potential productivity of new varieties into actual productivity, and ensure the increase and stability of rice production.

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Authors' Contributions

RF and HY designed the theoretical framework, methodology, data curation and edited the manuscript. YW and CZ conducted the data analysis and wrote the original draft manuscript. All authors read and approved the final manuscript.

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Availability of Data and Materials

The datasets used and/or analyzed during the current study are available fromthe corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests

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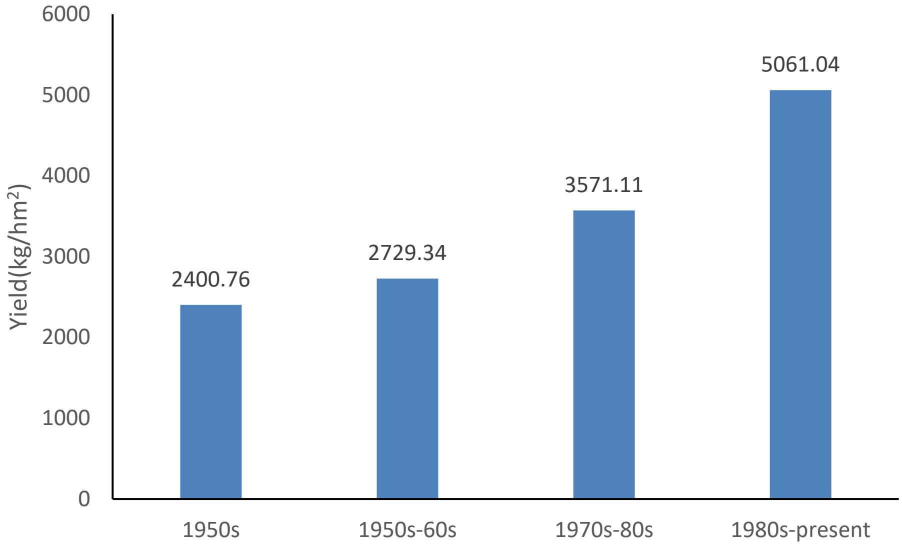

Figure 1. Yield changes of rice varieties in China over the past decades

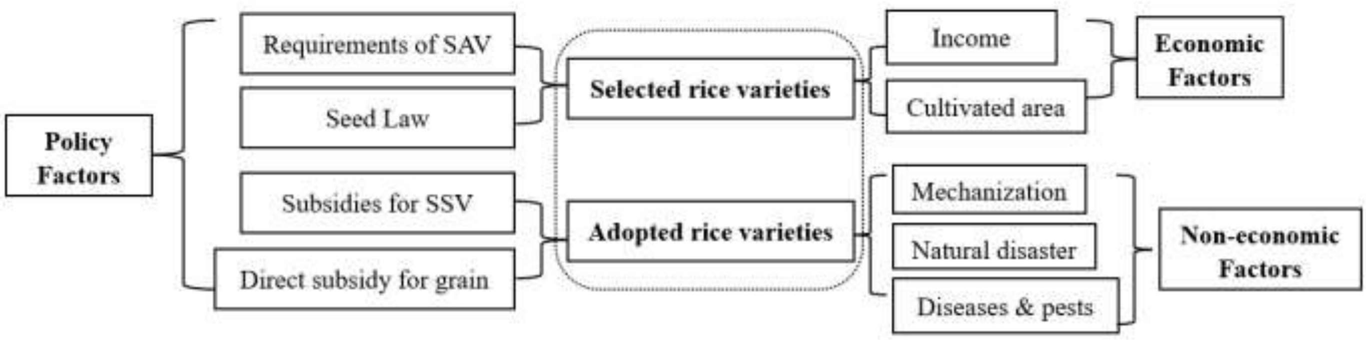

Figure 2. Theoretical frame for impact of government policies on selected and adopted rice varieties

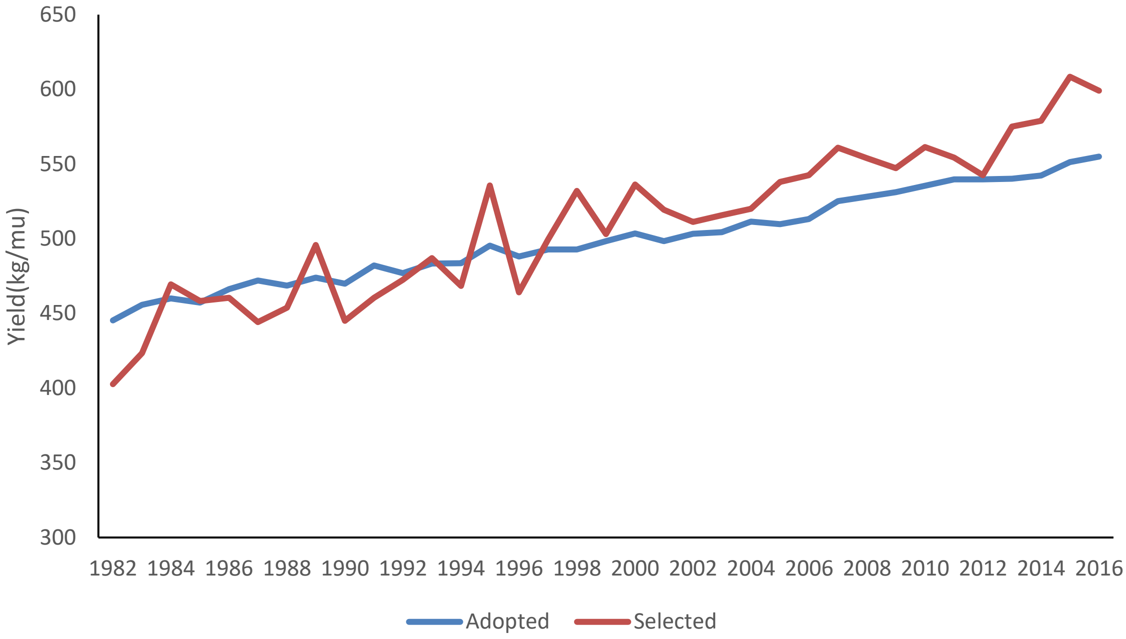

Figure 3. Yield trends of selected and adopted rice varieties from 1982 to 2016

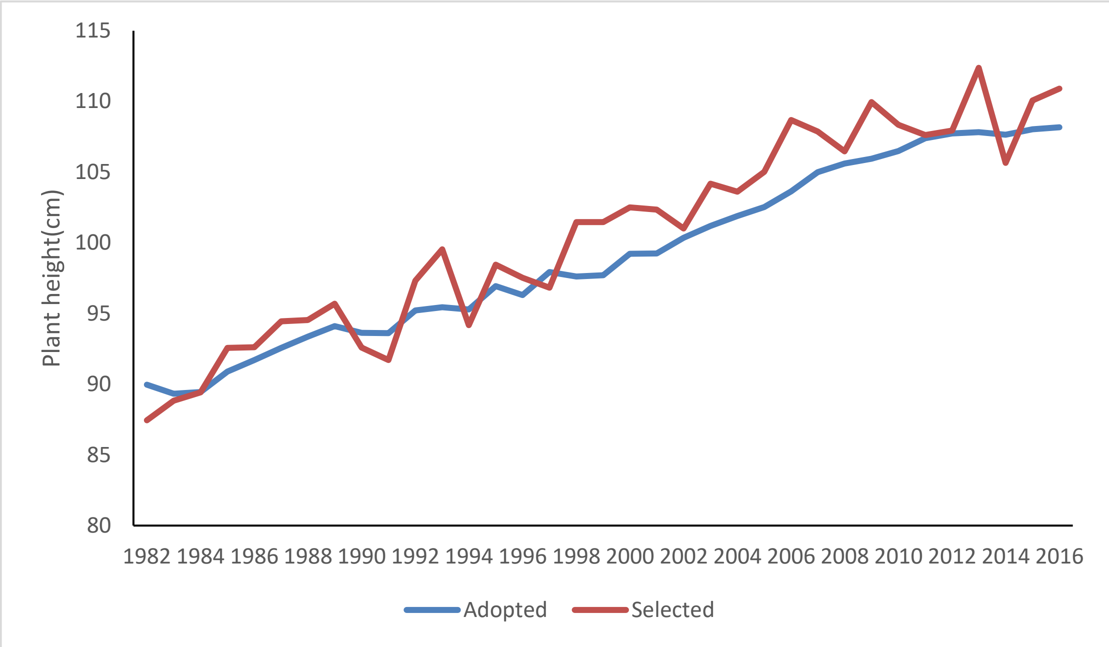

Figure 4. Plant height trends of selected and adopted rice varieties from 1982 to 2016

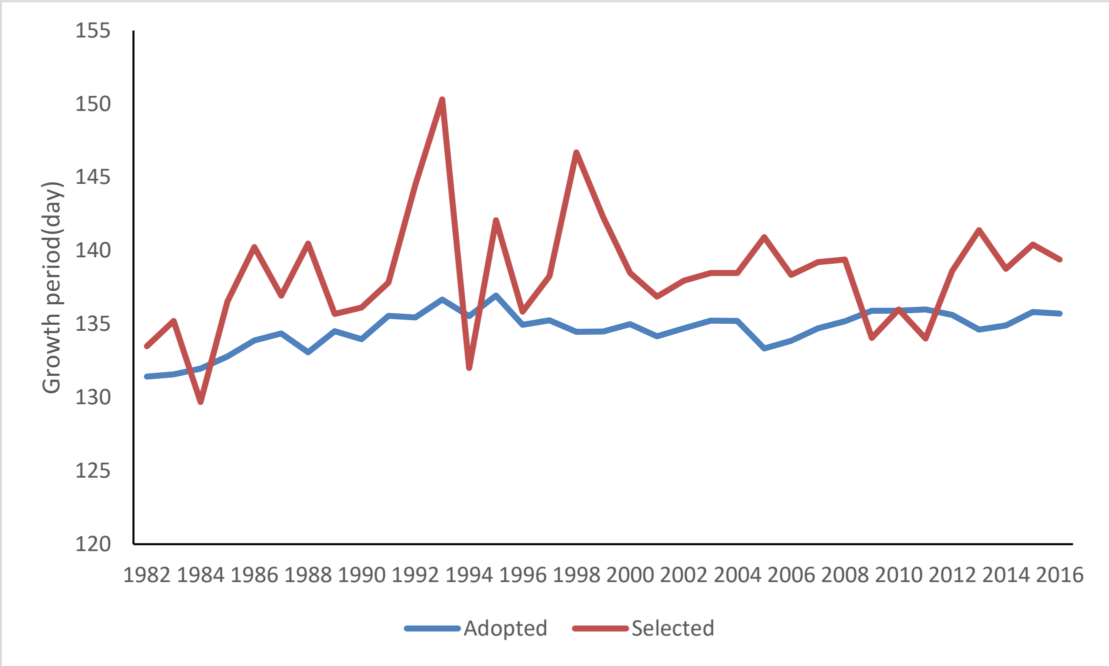

Figure 5. Growth period trends of selected and adopted rice varieties from 1982 to 2016

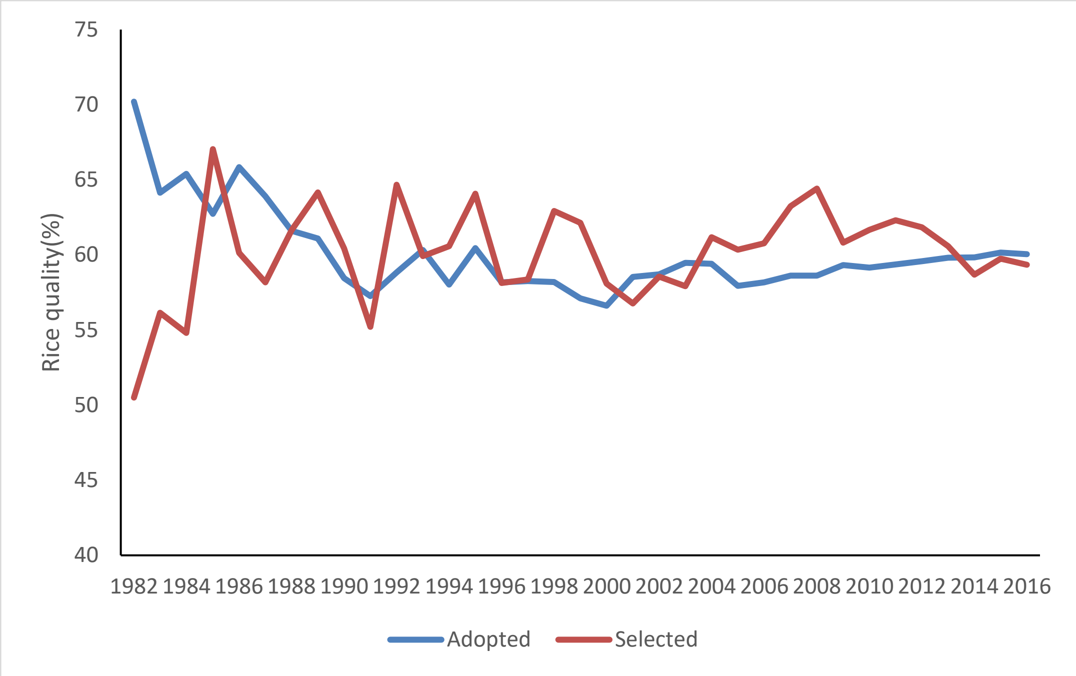

Figure 6. Rice quality trends of selected and adopted rice varieties from 1982 to 2016

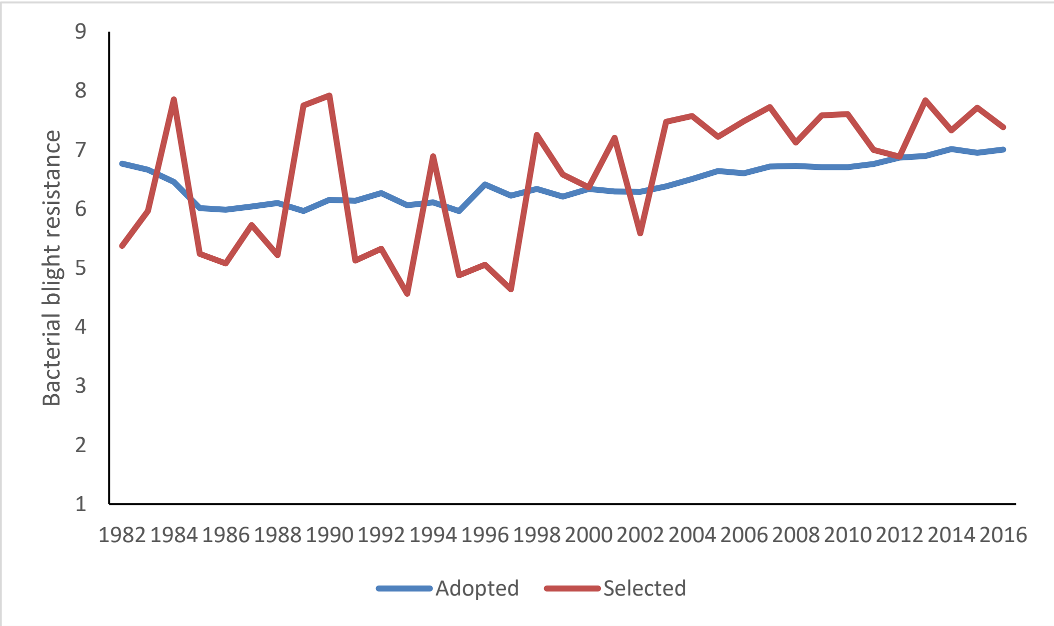

Figure 7. Bacterial blight resistance trends of selected and adopted rice varieties from 1982 to 2016

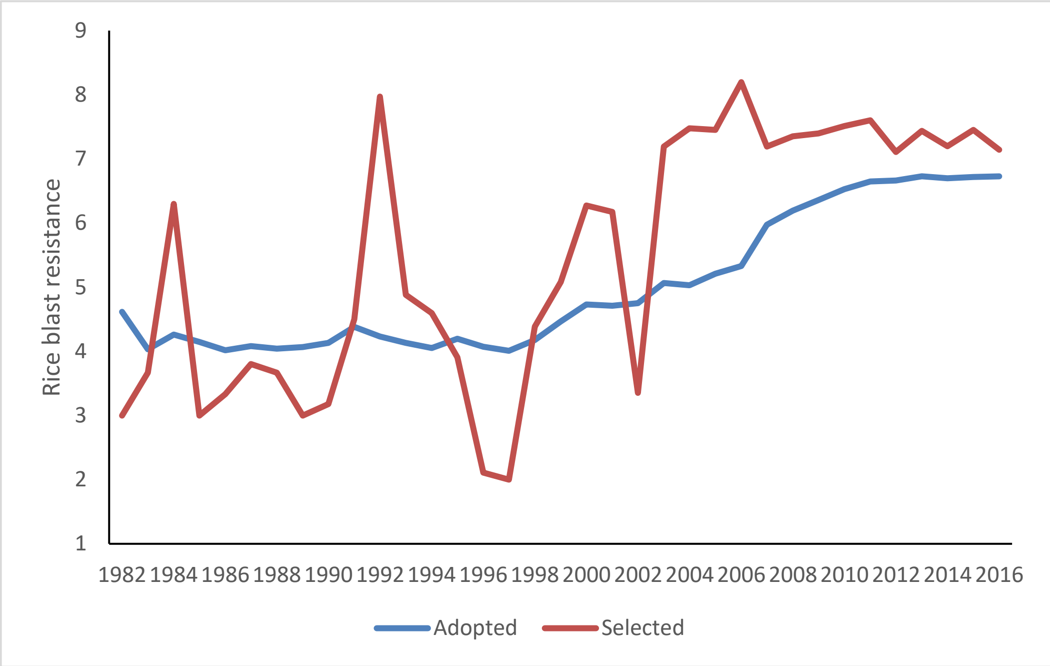

Figure 8. Rice blast resistance trends of selected and adopted rice varieties from 1982 to 2016

Table 1. Results of the impact of approval standards on the traits of approved rice varieties

	Yield （FE）	Plant height （FE）	Growth period （FE）	Head rice rate （FE）	Bacterial blight （FE）	Rice blast （FE）
Time trend	0.014***	0.005***	0.006***	-0.169***	-0.015***	0.012***
	(0.001)	(0.001)	(0.001)	(0.059)	(0.004)	(0.003)
Approval standard	-0.076***	-0.011	-0.034***	1.913**	0.177***	-0.626***
（1988-1996）	(0.016)	(0.010)	(0.010)	(0.816)	(0.039)	(0.033)
Approval standard	-0.081***	-0.024*	-0.021*	3.015***	0.225***	-0.554***
（1997-2001）	(0.019)	(0.013)	(0.013)	(0.974)	(0.065)	(0.049)
Approval standard	-0.138***	-0.030*	-0.023	7.195***	0.267***	-0.455***
（2002-2006）	(0.023)	(0.016)	(0.015)	(1.217)	(0.082)	(0.060)
Approval standard	-0.163***	-0.026	-0.060***	9.841***	0.347***	-0.474***
（After 2007）	(0.029)	(0.019)	(0.019)	(1.508)	(0.102)	(0.073)
Seed Law	0.008	-0.004	-0.063***	-4.947***	0.089**	0.257***
	(0.011)	(0.007)	(0.007)	(0.555)	(0.039)	(0.032)
Per capita	0.003	0.000	-0.005**	0.070	0.019*	-0.009
disposable income	(0.003)	(0.002)	(0.002)	(0.169)	(0.011)	(0.008)
Machine	-0.008**	-0.001	0.003	0.107	-0.003	0.042***
	(0.003)	(0.002)	(0.002)	(0.192)	(0.013)	(0.008)
Per capita arable	0.012	0.010	0.020***	0.250	-0.053*	-0.118***
land area	(0.009)	(0.007)	(0.006)	(0.530)	(0.031)	(0.023)
Flood	0.001	0.001**	0.000	0.041	0.001	-0.001
	(0.001)	(0.000)	(0.000)	(0.030)	(0.002)	(0.002)
Dry	-0.000	0.000**	-0.000	0.018	0.000	-0.001
	(0.000)	(0.000)	(0.000)	(0.014)	(0.001)	(0.001)
Diseases and	0.000	0.000	0.001	-0.007	-0.001	-0.066***
insect pests	(0.001)	(0.001)	(0.001)	(0.074)	(0.005)	(0.009)
Hybrid rice	0.001***	0.001***	0.001***	0.006	0.001*	-0.000
	(0.000)	(0.000)	(0.000)	(0.009)	(0.001)	(0.001)
Middle rice	0.000***	0.001***	0.001***	-0.004	-0.001	0.004***
	(0.000)	(0.000)	(0.000)	(0.007)	(0.000)	(0.000)
Late rice	0.001***	0.000***	0.000	0.036***	0.001	0.001**
	(0.000)	(0.000)	(0.000)	(0.008)	(0.001)	(0.000)
Indica rice	-0.001***	-0.001***	-0.002***	-0.084***	0.001***	-0.003***
	(0.000)	(0.000)	(0.000)	(0.008)	(0.000)	(0.000)
R^2	0.598	0.598	0.604	0.345	0.162	0.784

Note: The standard deviation in parentheses, "*", "**" and "***" indicate significant at the level of 10%, 5% and 1% respectively.

Table 2. Results of the impact of the subsidy policy for improved varieties on the traits of adopted rice varieties

	Yield (FE)	Plant height (FE)	Growth period (FE)	Head rice rate (FE)	Bacterial blight (FE)	Rice blast (FE)
Time trend	0.009***	0.003***	0.002***	-0.110**	0.005*	0.081***
	(0.001)	(0.000)	(0.000)	(0.050)	(0.002)	(0.010)
Subsidy policy for improved varieties	-0.040***	0.003	-0.008	1.214**	-0.025	-0.463***
	(0.010)	(0.005)	(0.005)	(0.599)	(0.035)	(0.128)
Direct subsidy policy for planting grains	-0.013	-0.002	-0.013***	2.028***	0.091**	-0.075
	(0.011)	(0.006)	(0.005)	(0.670)	(0.037)	(0.132)
Per capita disposable income	-0.013***	0.000	-0.001	0.122	0.003	0.059
	(0.005)	(0.002)	(0.002)	(0.305)	(0.016)	(0.066)
Machine	0.015***	-0.001	-0.000	-0.247	-0.000	-0.082
	(0.005)	(0.003)	(0.003)	(0.350)	(0.018)	(0.078)
Per capita arable land area	0.017	0.003	0.017***	-1.033	-0.149***	0.105
	(0.011)	(0.006)	(0.005)	(0.934)	(0.047)	(0.161)
Flood	0.000	0.001**	0.001**	-0.045	-0.006**	-0.001
	(0.001)	(0.000)	(0.000)	(0.037)	(0.002)	(0.007)
Dry	0.000	0.000**	0.000	0.028	-0.000	0.003
	(0.000)	(0.000)	(0.000)	(0.021)	(0.001)	(0.004)
Diseases and insect pests	0.000	0.000	0.001	-0.716***	0.003	-0.004
	(0.002)	(0.001)	(0.001)	(0.272)	(0.006)	(0.020)
Hybrid rice	-0.000***	0.000***	0.000	-0.019***	-0.001***	0.004***
	(0.000)	(0.000)	(0.000)	(0.006)	(0.000)	(0.001)
Mid-late rice	-0.000	0.002***	0.001***	0.112**	-0.004**	0.029***
	(0.001)	(0.000)	(0.000)	(0.052)	(0.002)	(0.006)
Indica rice	0.000	-0.000**	-0.000***	-0.036***	0.000	-0.002
	(0.000)	(0.000)	(0.000)	(0.010)	(0.000)	(0.002)
R^2	0.425	0.526	0.172	0.120	0.122	0.453

Note: The standard deviation in parentheses, "*", "**" and "***" indicate significant at the level of 10%, 5% and 1% respectively.

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