Journal of Integrative Agriculture 2024, 23(3): 1061–1074

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RESEARCH ARTICLE

Does Green Food Certification promote agri-food export quality? Evidence from China

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Abstract
The construction of a food certification system plays a vital role in upgrading export quality, which previous studies have largely overlooked. We match China's industry-level data of Green Food Certification with its HS6-digit export data of agri-food products to quantify the impact of Green Food Certification on export quality. We identify the significant and positive effect of Green Food Certification on export quality. The 2SLS estimation based on instrumental variables and a range of robustness checks confirm the validity and robustness of the benchmark conclusions. Further analysis discloses that Green Food Certification improves export quality by raising agricultural production efficiency and brand premiums. Heterogeneity analysis shows that the effect of Green Food Certification varies across regions, notably improving the quality of agri-food products exported to developed regions and regions with high levels of import supervision. Furthermore, among various product types, Green Food Certification significantly improves the export quality of primary products and products vulnerable to non-tariff measures. The above findings could guide the future development of agri-food quality certification systems, potentially leading to a transformation and promotion of the agri-food trade.

Keywords: Green Food Certification, agri-food products, green transformation, export quality, food labeling

1. Introduction

Agricultural trade is heavily protected in various countries. With the rise of trade protectionism and increased consumer demand for safe food, the international market has been raising the quality threshold for agricultural exports (Sun *et al*. 2021; Baylis *et al*. 2022; Suanin 2023). China is the world's leading producer and trader of agricultural products. However, it faces the following problems: low agricultural production efficiency, backward technology, low value-added agricultural exports, lack of internationally renowned brands, and an apparent lack of international competitiveness in agricultural products. Moreover, due to the late start of the construction of domestic quality standards and the lax quality control system, the export quality of Chinese agri-food products has been relatively backward. As a result, China's agri-food exports are frequently hit hard. This not only causes considerable losses to exporters, affecting export earnings and farmers' income, but also damages the international reputation of Chinese agri-food products and keeps

Received 20 February, 2023 Accepted 10 August, 2023
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doi: 10.1016/j.jia.2023.11.033

Chinese agri-food products at the lower end of the value chain. The National Strategic Plan for Quality Agriculture (2018–2022), the Guiding Opinions on Promoting High-quality Trade Development of the Central Committee of the Communist Party of China and The State Council, and the 14th Five-Year Plan for High-quality Foreign Trade Development of the Ministry of Commerce made important planning and deployment for the high-quality development of agricultural trade. The quality improvement of agricultural exports is an essential part of the high-quality development of agricultural trade and a significant driving force to accelerate the transformation of China from a large agricultural trade country to a strong agricultural trade country. Therefore, enhancing the quality of agricultural exports, improving the trade level and effectiveness, and promoting the climbing of the global value chain position have become vital issues to be solved.

To enhance the export quality of agricultural trade, accelerating the development of domestic agri-food standards is one of the most critical initiatives (Fiankor *et al.* 2021; Filippis *et al.* 2022; Bemelmans *et al.* 2023; Yang *et al.* 2023). Green Food Certification has become an essential tool for the Chinese government to improve the quality of agri-food exports in the context of tightening resource and environmental constraints, as it balances quality standards with environmental sustainability requirements. On the one hand, Green Food Certification aims to provide safe, high quality and nutritious food without pollution. It ensures the quality and environmental safety of agri-food products through strict supervision and control of production, processing, packaging, storage, and transportation and regulates the use of pesticides, chemical fertilizers, veterinary drugs, and additives to achieve source control of export product quality. On the other hand, Green Food Certification is conducive to introducing advanced agricultural technology and enhancing agricultural production efficiency, improving the technological content and value-added of export products. Moreover, Green Food Certification transmits quality signals to consumers in importing countries in the form of green labels, which helps to alleviate the information asymmetry between domestic producers and consumers in importing countries and establish an export market with high quality and high price (Nie *et al.* 2018), thus improving the quality of export products.

Currently, Green Food standards are widely accepted in China. As demonstrated in Fig. 1, the total number of certified firms of Green Food increased from 1,217 in 2001 to 23,493 in 2021 (Fig. 1-A), and the total number of certified products increased from 2,400 in 2001 to 51,071 in 2021 (Fig. 1-B), increasing by more than 18-fold and 20-fold, respectively. Fig. 2 exhibits the covered farmland of Green Food, and it can be seen that the farmland has increased rapidly from 2001 to 2021. These scale changes confirm the rapid development of Green Food Certification in China, indicating that consumers have recognized Green Food standards and that the demand for Green Food is vital.

The existing literature has discussed the economic and environmental benefits of Green Food Certification, including the impact on the selling price of agricultural products, farmers' income, and agricultural production behavior. As one important food safety control practice (Zhou *et al*. 2015), Green Food Certification has significant economic effects. Based on the original

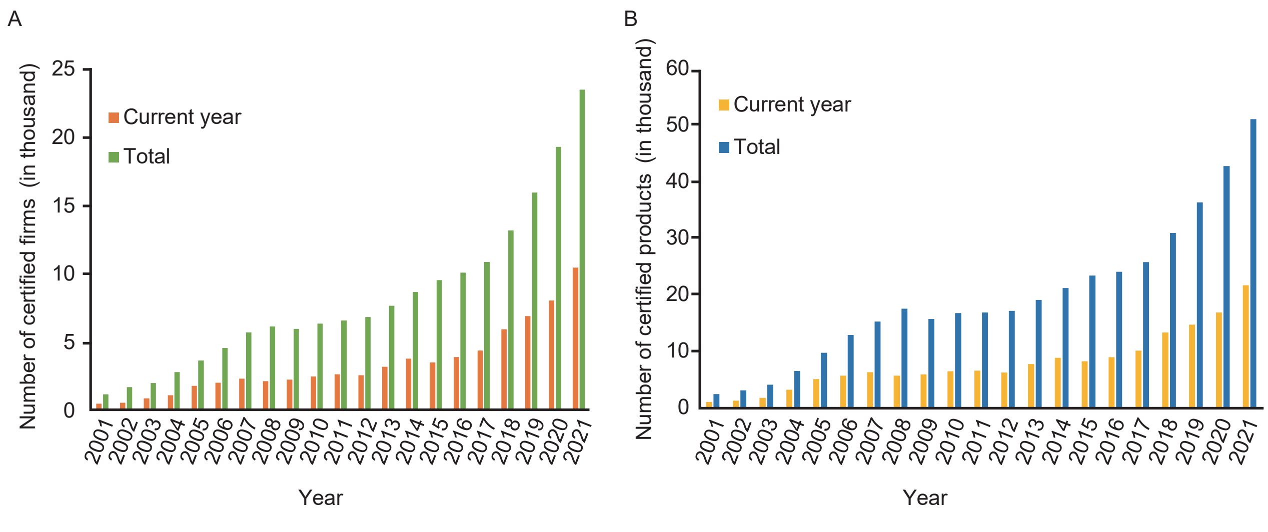

Fig. 1 The number of certified Green Food firms and products (2001–2021). A, the number of certified Green Food firms. B, the number of certified Green Food products. Source: China Green Food Development Center.

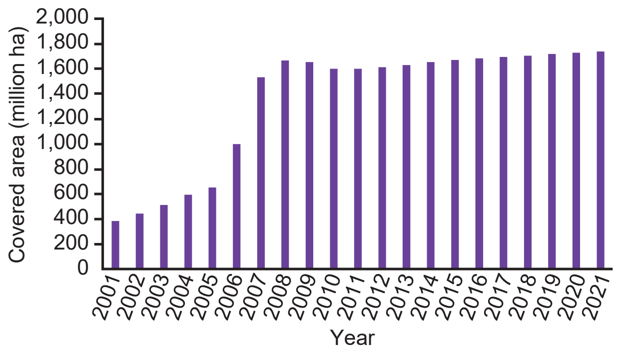

Fig. 2 Covered farmland of certified Green Food (2001–2021). Source: China Green Food Development Center.

survey data of 401 green tea farmers, Tran and Goto (2019) explored the impact of sustainability standards on sales prices, costs, and net income of green tea. The study found that although the certification leads to a dramatic increase in the costs of hired labor, it increases the selling price of green tea producers and ultimately increases each grower's net income. Liu *et al.* (2020) used household survey data on kiwi plantations in Henan Province, China, and reached a similar conclusion. However, the environmental effect of Green Food Certification has not yet reached a unified conclusion. Based on household survey data from six provinces in China, Nie *et al.* (2018) found that the production of certified food has no significant impact on Chinese farmers' consumption of chemical fertilizers or pesticides. The possible explanation is that farmers still lack knowledge of certification, and there are differences in the enforcement of laws and regulations in different regions. Some researchers have reached the opposite conclusion. Using vegetable survey data as samples, Li and Lu (2020) found that Green Food Certification positively impacts agricultural technology efficiency, and the specific channel mechanism includes premium incentives, cost pressure, and organizational support. Taking rice as a case, Ma *et al.* (2022) also found that the Green Food label has a significant price premium effect, which is conducive to constructing a positive market mechanism of "green label-high quality-good price", thus promoting the green transformation of agricultural production.

Although Green Food Certification has achieved rapid development in China and comes with a growing body of literature in relevant fields, few studies have explored the impact of Green Food Certification on international trade. So, has China's growing Green Food Certification actually improved the quality of export products? What are the specific channels? These are worthy of attention and of great significance. This paper intends to supplement this, which is different from the previous literature that focuses on the trade impact of the import country's standards or the non-tariff measures (NTMs) (Bao and Zhu 2014; Crivelli and Groeschl 2016; Hejazi *et al.* 2022).

First, our results evidence that Green Food Certification plays a vital role in transforming and upgrading the agri-food trade, which has been largely overlooked by previous studies. We ascertain that Green Food Certification can promote the export quality of agri-food products. The results are still remarkably valid after considering a range of robustness checks, such as replacing the primary independent and dependent variables, adding high-dimensional fixed effects, and adjusting the sample period. In addition, we consider the possible endogeneity problems in the model and use instrumental variables to re-estimate the baseline equation, confirming the positive impact of Green Food Certification on export quality. The results reveal that the development of national Green Food Certification has a substantial export quality upgrading effect, which helps construct the quality comparative advantage of agri-food exports, thereby promoting the green transformation of agricultural production and upgrading the position in global value chains.

Also, we investigate three specific mechanisms by which Green Food Certification impacts export quality and empirically test them. Our analysis suggests that Green Food Certification upgrades the export quality by enhancing agricultural production efficiency and establishing brand premium advantages. These findings provide further insight into the relationship between certification and export quality.

Moreover, existing empirical studies on Green Food Certification are mainly based on provincial-level data (Yu *et al.* 2021) or household survey data (Li and Lu 2020). However, by matching the industry-level data of Green Food Certification with the HS6-digit agri-food export data, our analysis is based on a large sample covering 162 importing countries, 33 certified industries, and 603 agri-food products from 2006 to 2020. Compared with previous data, our sample contains a broader range of agri-food products and can reflect the differences between different industries with more specific and targeted findings.

In addition, by region and product, we further explore the heterogeneous impact of development status, importer regulation, processing level, and vulnerability to NTMs on the quality-enhancing effect of Green Food Certification. We disclosed the following conclusions. First, Green Food Certification has a more significant effect on improving the quality of agri-food products exported to developed markets or markets with high levels of importer regulation. This is partly because these regions generally maintain higher certification standards and impose stricter quality control on imported products. Therefore, the nation's Green Food standards need to be coordinated upwards with a view toward exporters strictly abiding by Green Food standards driven by profit. Second, Green Food Certification likely affects the export quality of primary products more than processed products. This is because ensuring quality control among processed products and guaranteeing green quality across an array of processed raw materials are notably more challenging compared to primary products. Third, Green Food Certification has a significant positive impact on the export quality of products vulnerable to NTMs, implying that Green Food Certification has important implications for breaking through international trade barriers for agri-food products, consistent with Martinez and Banados (2004).

Finally, our study supplements existing literature related to export quality, which has become a hot topic in recent years. A large body of existing literature studies the effect of foreign direct investment (FDI), institutional quality, and technological innovation on export quality (Blyde *et al.* 2018; Curzi *et al.* 2020; Dhahri and Omri 2020). Some studies have paid attention to the impact of agri-food standards, while they mainly focus on international standards construction (Ferro *et al.* 2015; Kareem and Martínez-Zarzoso 2020; Wang *et al.* 2022). Few studies have discussed the impact of domestic quality standards. Therefore, we plan to fill this gap. We attempt to put Green Food Certification and export quality under a unified framework, which differs from previous literature focusing on trade impacts brought about by standards or NTMs imposed by importing countries (Wei *et al*. 2012; Bao and Zhu 2014; Crivelli and Groeschl 2016; Hejazi *et al.* 2022). Also, the Green Food label is a typical food label. Since several existing studies have examined the impact of food labeling on welfare among farmers and consumers, our research combines food labeling with export quality, providing new evidence for the welfare effect of food labeling.

2. Data and methods

2.1. Empirical strategy

Benchmark regression model To examine agri-food product exports impacted by Green Food Certification, we proposed a benchmark regression equation:

$$Exquality_{jkt}=\alpha+\beta_1 Greenrate_{Kt}+\beta_2 CV_{jkt}+\mu_j+\delta_k+v_t+\varepsilon_{jkt} \quad (1)$$

where, j, t, and k denote the importing country or region, year, and HS6-digit agri-food product category, respectively. K denotes 33 detailed agri-food industries. CV_{jkt} is a range of control variables. β denotes the coefficient, α denotes the constant item, and ε_{jkt} denotes the error item. We controlled for a range of potentially omitted variables affecting agri-food export: importer fixed effects μ_j, product fixed effects δ_k, and year fixed effects v_t in eq. (1).

Theoretical mechanism and model Subsequent sections explore the impact path of Green Food Certification on the export quality of agri-food products from the perspectives of producers and consumers. This paper concludes that Green Food Certification mainly improves the export quality of agri-food products by enhancing agricultural production efficiency and establishing brand premium advantages, as shown in Fig. 3.

On the one hand, Green Food Certification helps increase agri-food product export quality by enhancing agricultural production efficiency, mainly in three aspects.

First, Green Food Certification requires production to be carried out according to uniform criteria, which promotes industrial agglomeration throughout green agriculture, achieving economies of scale and improving operational efficiency (Yang and Li 2021). Second, Green Food Certification, once established, comprises strict standards, rigorously controlling the quantity and type of pesticides, fertilizers, and other inputs in the agricultural production process. It is conducive to regulating agricultural production behavior, conserving resource inputs, optimizing production factors allocation, transforming extensive agriculture into intensive

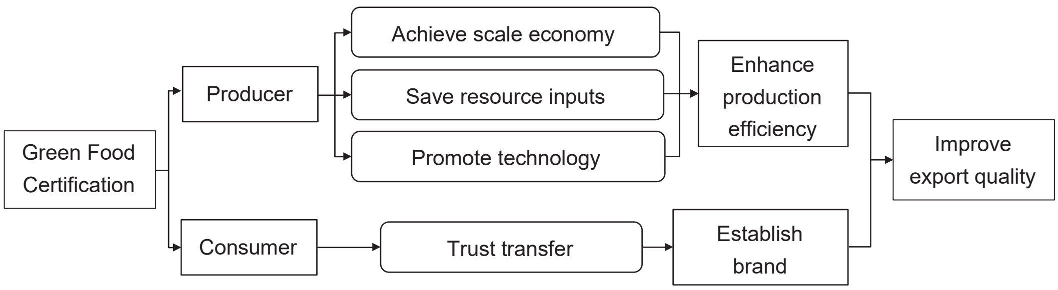

Fig. 3 Theoretical framework of Green Food Certification affecting agri-food export quality.

production, and ultimately raising agricultural production efficiency (Li and Lu 2020). Finally, green agriculture strategies call for modern agricultural equipment, advanced green technologies, and modern management concepts, which are essential to promoting agricultural technology innovation (Bac *et al.* 2018).

Agricultural production efficiency reflects the technical and management level of agricultural production. Based on the firm heterogeneity model, high-productivity enterprises have lower marginal production costs. Therefore, at a given price level, enterprises with higher production efficiency export more high-quality products (Fan and Guo 2015). In addition, the higher the production efficiency of exporters, the easier it is to compete in a market and absorb R&D costs, which in turn yield product upgrades and brand recognition worldwide (Antoniades 2015). In short, higher agricultural production efficiency is associated with higher export product quality.

Accordingly, we propose Hypothesis 1: Green Food Certification improves the export quality of agri-food products by enhancing agricultural production efficiency.

On the other hand, Green Food Certification affects agri-food product quality among exports by showcasing brand premium advantages.

Referring to Garvin (1984), the export quality of agri-food products includes not only objective characteristics, such as flavor and nutritional value, but also brand recognition, history, and other factors. Brand cultivation means competitive advantage and rapid export upgrades, controlling against cut-throat competition caused by homogenization among agri-food products (Jiang 2022). In addition, a great brand image and reputation help capture international market shares and assure export expansion. It brings direct economic benefits to enterprises and provides support for product development and export quality upgrades (Wei 2023). Therefore, cultivating brand advantages can improve export product quality (Shi and Shao 2014).

Green Food Certification conveys product quality information certified by the government to consumers. According to trust transfer theory, where these products are sold as imports, consumers tend to apply their trust in the government or certification agencies to those certified agri-food products, esteeming Chinese agri-food products and preferring to buy those available. In the long run, Green Food Certification is conducive to brand evolution and raised standards for export quality.

Accordingly, we propose Hypothesis 2: Green Food Certification stewards brand advantages measurable as export quality among agri-food products.

As discussed in the prior section, Green Food Certification has a positive impact on the export quality of agricultural food products by improving agricultural production efficiency and promoting brand premiums. Following research conducted by Jin and Shi (2022), we tested these mechanisms by regressing the mechanism variables on the core independent variable. The model follows:

$$Mediate_{jkt}=\gamma_0+\gamma_1 Greenrate_{Kt}+\gamma_2 CV_{jkt}+\mu_j+\delta_k+v_t+\varepsilon_{jkt} \quad (2)$$

where, $Mediate_{jkt}$ denotes possible channels, including agricultural productivity (TFP_{Kt}) and brand advantage ($Brand_{kt}$).

2.2. Variables

Dependent variable $Exquality_{jkt}$ is the export quality of product k from China to country or region j in year t. Following Khandelwal *et al.* (2013), we estimated the export quality of agri-food products using the following equation:

$$\ln X_{jkt}=-\sigma \ln P_{jkt}+\chi_j+\eta_k+\xi_t+\varepsilon_{jkt} \quad (3)$$

where, $\ln X_{jkt}$ and $\ln P_{jkt}$ denote the natural logarithms of export quantity and price of product k to country or region j in year t. χ_j, η_k, and ξ_t denote importer, product, and year-fixed effects, respectively. ε_{jkt} denotes the error item, including the export quality information. σ denotes the elasticity of substitution. Then, the quality of product k exported from China to other country or region j in a given year t is defined as:

$$Exquality_{jkt}=\frac{\hat{\varepsilon}_{jkt}}{(\sigma-1)} \quad (4)$$

where, $\hat{\varepsilon}_{jkt}$ can be estimated from Ordinary Least Squares (OLS) regression, and σ can be derived from the results of Broda and Weinstein (2006).

Independent variable $Greenrate_{Kt}$ is the rate of Green Food Certification of industry K in year t, which is defined as the ratio of the yield of certified Green Food in industry K to its total yield:

$$Greenrate_{Kt}=\frac{Greenyield_{Kt}}{Totalyield_{Kt}} \quad (5)$$

Mechanism variables The mechanism variables are as follows: (1) Agricultural production efficiency (TFP_{Kt}), measured by the total factor productivity of industry K in year t. For this estimate, we used the DEA-Malmquist index widely used throughout the literature. Following Zheng and Cheng (2021), output is measured by agri-food product yield by area, while inputs are measured according to labor costs by area as well as the material and service costs by area. The material and service costs include expenses for seed, fertilizer, pesticide, agricultural film, machinery, and fuel. (2) Brand premiums ($Brand_{kt}$). Green labels can effectively reduce information asymmetry between producers and consumers, marketing for high quality and high price tolerance, and increase foreign consumers' willingness to pay a premium for agri-food products (Jiang 2022). Relative price is an effective measure of brand premiums. Greater brand recognition means a stronger willingness to purchase those products at relatively high prices. Therefore, following Xu (2010), we used relative prices to measure each brand's competitive advantage. The brand advantage is defined as:

$$Brand_{kt}=\frac{P_{kt}}{\sum_{n\epsilon C_j}\mu_{nk}P_{nk}} \quad (6)$$

where, P_{kt} denotes the export price of product k in China, $\sum_{n\epsilon C_j}\mu_{nk}P_{nk}$ denotes the weighted average value of the export price of product k in all countries, and μ_{nk} denotes country n's global export market share.

Control variables Following the literature (Zeng and Xu 2022), we selected the following variables at a national level as most relevant to this study: (1) ln*GDP* is the natural log of the economic scale of the importing country. Citizens of countries with higher standards of living place higher demands on product quality while also maintaining a few competitive bases of their own production and diversified logistics for high-quality products internationally. (2) ln*Pop* is the natural log of the population of the importing country. A country with a larger population demands a wider array and mature segmentation among agricultural products. (3) ln*Free* is the natural log of the economic freedom of the importing country. The improvement of economic freedom of importing countries can reduce the trade cost of Chinese agricultural products, thereby increasing opportunities among Chinese exporters themselves to seize profits, leaving a surplus that could be applied selectively to export quality.

Moreover, we also selected two product-level variables. (1) ln*TI* is the natural log of the total import value of all countries with certain products traded, reflecting global demand. (2) *RCA* is the revealed comparative advantage of product k exported by China, reflecting China's international competitiveness in agri-food products. *RCA* is defined as follows: $RCA=(E_{ikt}/\sum_k E_{ikt})/(\sum_i E_{ikt}/\sum_k\sum_i E_{ikt})$, where, t denotes time, k denotes specific agricultural product, i denotes exporter of product k, and E_{ikt} denotes the export value of product k by country i in year t. Generally, products in heavy demand among importers and products having comparative advantages in contested markets tend toward higher export quality.

Table 1 presents the descriptive statistics of each variable.

Table 1 Variable descriptive statistics

Variables[1)]	Mean	Std. dev	Min	Max	Observations
Exquality	0.006	1.765	–20.775	14.786	310,134
Greenrate	0.036	0.055	0.000	0.345	310,134
ln*GDP*	25.280	1.963	18.762	29.153	310,134
ln*Pop*	9.441	1.639	4.263	12.519	310,134
ln*Free*	4.143	0.164	3.063	4.493	310,134
ln*TI*	7.202	2.804	–6.908	15.337	310,134
ln*RCA*	–0.214	1.951	–15.908	3.035	310,134

[1)] *Exquality*, export quality; *Greenrate*, rate of Green Food Certification; *Pop*, population of the importing country; *Free*, economic freedom of the importing country; *TI*, total import value of product *k*; *RCA*, revealed comparative advantage of product *k*.

2.3. Data

For the first time, we matched HS6-digit agri-food export data from CEPII with the Green Food Certification data by industry to which the HS6-digit agri-food products belong. The final samples include 162 importing countries, 33 industries, and 603 agri-food products over a period from 2006 to 2020. The detailed matching process is as follows: First, we selected agri-food products from CEPII under the following HS2-digit groups: HS01-04, HS07-12, HS15-24. Then, according to the names of the HS4-digit groups in which the HS6-digit agri-food products belong, we matched HS6-digit export data with green certification data. Finally, we gathered samples from 33 industries and 603 HS6-digit agri-food products (Appendix A).

Green certification data come from Annual Statistical Report of Green Food (2006–2020) published by the China Green Food Development Center. Then, we interpolated observations to fill in a few missing observations in 2011 and 2012. Production data of agri-food products are from the *China Rural Statistical Yearbook* and the *Yearbook of China Agricultural Products Processing Industries*. China's agri-food export data at the HS6-digit level is obtained from the CEPII-BACI database. GDP indicators are from the World Bank's World Development Indicators (WDI), using constant prices in 2015. The population data are from the CEPII-Gravity database. The index of economic freedom of importers comes from the Heritage Foundation. The exchange rate is derived from the National Accounts Main Statistics Database. Finally, product-level indicators come from the CEPII-BACI database. The input data of chemical fertilizers and pesticides comes from the National Farm Product Cost-benefit Survey.

3. Results

3.1. Benchmark regression results

We use OLS regression to estimate the benchmark specification. Year, importer, and product fixed effects are included to control for the potential omitted variables. Table 2 presents our baseline results. In column (1), the estimated coefficient of Green Food Certification (*Greenrate*) is 0.030 and is statistically significant at the 1% level, indicating positive outcomes on export quality when Green Food Certification is present. In column (2), control variables are included, and the estimated coefficient of Green Food Certification is reported as still significantly positive, which suggests that Green Food Certification drives export quality within an array of agri-food products.

Furthermore, we impose a null hypothesis H_0: $\beta_2=\beta_3=\beta_4=\beta_5=\beta_6=0$ and use the likelihood ratio test (LR test) to select the form of eq. (1). The results show that the value of the likelihood ratio statistic is 29,876.540, which rejects hypothesis H_0 at the 1% level, indicating the model with control variables of column (2) is more appropriate. Therefore, the regression equations below all adopt the form of column (2) unless otherwise specified.

3.2. Robustness checks

To test baseline regression results for robustness, we conducted a range of checks.

Replacing the main independent variable and dependent variable First, we re-estimated our baseline specification by replacing the main independent variable with the output of Green Food Certification and the ratio of Green Food Certificates to total output based on available data. The results are displayed in columns (1) and (2) of Table 3, which point to positive and statistically significant impacts of Green Food Certification on export quality.

Also, referring to the literature (Fan *et al.* 2015; Zeng and Xu 2022), we set the elasticity of substitution to 5 and re-estimate agri-food export quality. Results are shown in column (3) of Table 3. Since the exchange rate is an important factor affecting exports, we further control the exchange rate in column (4) of Table 3. Estimated results in columns (3) and (4) are consistent with the baseline regression.

Adding high-dimensional fixed effects To rule out omitted variable biases in our baseline specification, we further controlled the importer-year and importer-product fixed effects to reduce estimation bias caused by omitted variables. These results are displayed in columns (1) and (2) of Table 4. The coefficients on Green Food Certification are positive and statistically significant at the 1% level, implying results robust.

Adjusting the period of the sample Our sample period is 2006–2020, and the missing data from 2011 to 2012 are filled in by interpolation. To avoid interpolated data interference, we eliminated the data from 2011 and 2012 and divided the sample period into 2006–2010 and 2013–2020 for re-estimation, respectively. As shown in columns (3) and (4) of Table 4, the impacts of Green Food Certification on export quality are both significantly positive; therefore, the results are robust.

Excluding the impact of other domestic green policies in the same period During the same period, China has also implemented other green policies that may have a potential impact on agri-food export quality, which may interfere with baseline results. Therefore, we sort out three policies that may interfere with baseline results

Table 2 The effect of Green Food Certification on export quality (Exquality)

Variables[1)]	(1) *Exquality*	(2) *Exquality*
Greenrate	0.030***	0.016***
	(0.005)	(0.005)
ln*GDP*		–0.287***
		(0.037)
ln*Pop*		0.259***
		(0.049)
ln*Free*		0.070
		(0.074)
ln*TI*		0.323***
		(0.002)
ln*RCA*		0.162***
		(0.006)
Constant	0.003	2.232***
	(0.003)	(0.866)
Year fixed effects	Yes	Yes
Importer fixed effects	Yes	Yes
Product fixed effects	Yes	Yes
Observations	310,133	310,133
R^2	0.009	0.100
LR test		29,876.540

[1)] *Greenrate*, rate of Green Food Certification; *Pop*, population of the importing country; *Free*, economic freedom of the importing country; *TI*, total import value of product *k*; *RCA*, revealed comparative advantage of product *k*.
Robust standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

Table 3 Robustness check results by replacing the main independent and dependent variable

Variables[1)]	(1)	(2)	(3)	(4)
Greenrate	0.034***	0.003***	0.005***	0.005***
	(0.008)	(0.001)	(0.002)	(0.002)
Control variables	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Importer fixed effects	Yes	Yes	Yes	Yes
Product fixed effects	Yes	Yes	Yes	Yes
Observations	305,199	310,133	310,133	299,885
R^2	0.102	0.100	0.163	0.165

[1)] *Greenrate*, rate of Green Food Certification.
Robust standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

Table 4 Robustness check results by adding high-dimensional fixed effects and adjusting the period of the sample[1)]

Variables[2)]	(1) *Exquality*	(2) *Exquality*	(3) 2006–2010	(4) 2013–2020
Greenrate	0.017***	0.016***	0.044***	0.021***
	(0.005)	(0.004)	(0.014)	(0.008)
Control variables	Yes	Yes	Yes	Yes
Year fixed effects	No	Yes	Yes	Yes
Importer fixed effects	No	No	Yes	Yes
Product fixed effects	Yes	No	Yes	Yes
Importer-Year fixed effects	Yes	No	No	No
Importer-Product fixed effects	No	Yes	No	No
Observations	310,131	299,791	71,663	170,601
R^2	0.104	0.631	0.126	0.105

[1)] *Exquality*, export quality.
[2)] *Greenrate*, rate of Green Food Certification.
Robust standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

Table 5 Robustness check results by excluding the impact of other domestic green policies in the same period[1)]

Variables[2)]	(1) *Exquality*	(2) *Exquality*	(3) *Exquality*
Greenrate	0.016***	0.016***	0.016***
	(0.005)	(0.005)	(0.005)
Ferti×Post2015	0.000		
	(0.000)		
HSF_{Kt}		0.028	
		(0.019)	
GZ_{Kt}			0.048*
			(0.028)
Control variables	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Importer fixed effects	Yes	Yes	Yes
Product fixed effects	Yes	Yes	Yes
Observations	310,133	310,133	310,133
R^2	0.100	0.100	0.100

[1)] *Exquality*, export quality.
[2)] *Greenrate*, rate of Green Food Certification; *Ferti*, average fertilizer use on farmland; *Post2015*, dummy variable (1 if year≥2015); HSF_{Kt}, dummy variable indicating whether industry *K* is affected by the high-standard farmland construction policy in year *t*; GZ_{Kt}, dummy variable indicating whether industry *K* is affected by functional zones for grain production policy in year *t*.
Robust standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

during the sample period and try to rule out their impact. First, in 2015, when the Ministry of Agriculture and Rural Affairs of China announced the Action Plan for Zero Growth in Fertilizer Use by 2020, zero-growth policies took effect to reduce chemical fertilizer usage. Second, in 2012, the same ministry promulgated the High-standard Basic Farmland Construction Standards (Trial) and implemented those a year later. Third, dating back to 2008, the Development and Reform Commission of China established three functional zones for grain production in their Outline of the Medium-and Long-term Plan for National Food Security (2008–2020).

To exclude interference stemming from these policies: (1) Since the zero-growth action of chemical fertilizers is mainly reflected in the amount of chemical fertilizer input in agricultural production, following He *et al*. (2023), we add the interaction term between average fertilizer use on farmland (*Ferti*) and the dummy variable *Post*2015 (set to 0 before 2015, and 1 otherwise) as a control variable in our baseline model. The results are shown in column (1) of Table 5. (2) Since the policy of high-standard farmland construction "focuses on the major grain-producing areas", following Lu *et al.* (2022), we add a dummy variable HSF_{Kt} to our baseline model to indicate whether industry *K* is affected by the policy in year *t*. If the product belongs to the grain industry during and after 2013, HSF_{Kt} is equal to 1; otherwise, it is equal to 0. The results are shown in column (2) of Table 5. (3) Similarly, since the main goal of functional zones for grain production is to increase the grain production capacity, we introduce a dummy variable GZ_{Kt} in the benchmark model to indicate whether industry *K* is affected by the policy in year *t*. If the product belongs to the grain industry in and after 2008, GZ_{Kt} is equal to 1; otherwise, it is equal to 0. Results are shown in column (3) of Table 5, which shows baseline results remaining robust without the aforementioned disturbances.

Excluding the impact of sanitary and phytosanitary (SPS) or technical barriers to trade (TBT) measures The SPS and TBT measures implemented by importing countries are important thresholds for agri-food products to enter the international market and may also affect export quality upgrades. To control for interference from SPS and TBT, we add the natural log of the number of SPS measures implemented by the importing country (ln*SPS*) and the natural log of the number of TBT measures implemented by the importing country (ln*TBT*) in our baseline model. Results are shown in columns (1)–(3) in Table 6.

Excluding the impact of green certifications in trade In addition to domestic green policies, internationally-issued green certifications could also interfere with our results. Therefore, we pick out relevant international certifications and try to exclude their influence.

There are mainly five types of international green certifications liable to interfere with our results. First, the animal welfare certification, such as Approved Animal Welfare (AWA) since 2006, sets quality and safety standards for animal-derived food (e.g., meat, eggs, and dairy products) by improving animal welfare and breeding standards to minimize veterinary drug residues,

Table 6 Robustness check results by excluding the impact of sanitary and phytosanitary (SPS) or technical barriers to trade (TBT) measure[1)]

Variables[2)]	(1)	(2)	(3)
	Exquality	*Exquality*	*Exquality*
Greenrate	0.016***	0.016***	0.016***
	(0.005)	(0.005)	(0.005)
ln*SPS*	0.004		0.005
	(0.005)		(0.005)
ln*TBT*		–0.005	–0.006
		(0.004)	(0.004)
Control variables	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Importer fixed effects	Yes	Yes	Yes
Product fixed effects	Yes	Yes	Yes
Observations	310,133	310,133	310,133
R^2	0.100	0.100	0.100

[1)] *Exquality*, export quality.
[2)] *Greenrate*, rate of Green Food Certification.
Robust standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

Table 7 Robustness check results by excluding the impact of green certifications in trade[1)]

Variables[2)]	(1)	(2)	(3)
	Exquality	*Exquality*	*Exquality*
Greenrate	0.014***	0.013**	0.014***
	(0.005)	(0.005)	(0.005)
Control variables	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Importer fixed effects	Yes	Yes	Yes
Product fixed effects	Yes	Yes	Yes
Observations	232,822	244,171	232,822
R^2	0.109	0.121	0.109

[1)] *Exquality*, export quality.
[2)] *Greenrate*, rate of Green Food Certification.
Robust standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

bacteria, viruses, and parasite contamination. Second, the aquatic product certification, including aquaculture ASC certification and MSC certification, encourages sustainable development in industries related to marine ecosystems. Third, the Round Table for Responsible Soy (RTRS) advocates industrial transparency about using natural or artificial methods to produce and process soybeans. Fourth, the Roundtable of Sustainable Palm Oil (RSPO) promotes the production and consumption of sustainable palm oil products. Fifth is the international organic certification, mainly including USDA organic certification, EU organic certification (ECOCERT), German BIO organic certification, and Japanese JAS certification.

Since the first four certifications cover different products, we eliminated animal-derived products (including meat, dairy products, and eggs), aquatic products, soybeans, and palm oil in the sample and re-estimated the model to minimize interference caused by these policies. Results are displayed in column (1) of Table 7. However, considering such a wide range of products included in the international organic certification, we cannot rule out the certification or its impact simply by excluding those products directly targeted. Meanwhile, such standards are often levied against products coming into countries with long-term concerns expressed about safety and sustainability. Therefore, we excluded the samples whose importing countries were the United States, the EU member states (including Germany), and Japan and re-estimated the model to control the impact of this set of policies. Results are shown in column (2) of Table 7. Finally, considering the impact of all discussed international certifications in the prior sessions, we excluded all these products and regions at the same time and re-estimated our model. The results are displayed in column (3) of Table 7. The results in columns (1)–(3) of Table 7 suggest that our baseline results are still reliable without impact from this set of four international certification types.

3.3. Endogeneity analysis

Although our econometric model and estimates are insulated from endogeneity concerns to a large extent by including a rich set of fixed effects and controlling for other important variables affecting the model, they might be biased by reverse causality. Expressly, the previous baseline regression confirms the positive impact of green certification on export quality; however, export quality may, in turn, affect the choice of the products certified, thereby affecting the level of green certification. To address these endogeneity concerns, we resorted to an instrument variable (IV) estimation strategy.

Following Shen *et al.* (2016), we take the Green Food Label Management Measures issued by the Ministry of Agriculture of China in 2012 as a policy shock and use the product of the dummy variable of this shock and the green certification level in the initial year of the sample (*Shock*×*Greenrate2006*) as an instrumental variable. *Shock* denotes a binary dummy variable for the policy shock, equal to 1 if the year is before 2012 and 0 if otherwise. *Greenrate2006* denotes the level of Green Food Certification in 2006. The instrumental variable satisfies the correlation and exogeneity assumptions. First, policy shocks have different impacts on Green Food Certification in different agri-food industries. As the level of Green Food Certification increases throughout the industry, the impact of policy shocks on the industry becomes smaller. Therefore, the instrumental variable satisfies the correlation assumption. Moreover, a policy is mainly formulated and implemented by the government, which is relatively exogenous, and the initial level of Green Food Certification is also exogenous to the later export behavior. Therefore, the instrumental variable also satisfies the exogenous assumption.

Based on the analysis above, we estimate the model using two-stage least squares estimations (2SLS) and IV estimates, as presented in Table 8. First-stage regression shows coefficients of the instrumental variable to be significant at the 1% level, while the value of the *F* statistic is significantly greater than the empirical test value (10). Second-stage regression suggests that the value of the Kleibergen-Paap Wald *F* statistic has a significantly greater value than the critical 10% level of the Stock-Yogo weak identification test (16.38). The above results indicate that the selection of the instrumental variable is reasonable. The second-stage regression suggests that the coefficient of Green Food Certification (*Greenrate*) is significantly positive. Our estimation is robust since the results remain unchanged when we include instrumental variables.

3.4. Heterogeneity analysis

Product heterogeneity First, following Regmi *et al.* (2005), we divided agri-food products into primary products and processed products, and here display results in columns (1) and (2) of Table 9. It can be seen coefficients on Green Food Certification ($Greenrate_{Kt}$) are both positive and statistically significant. In column (1), the magnitude of the positive effects is larger for primary products compared with processed products. This is because green certification for primary products mainly focuses on the production side, whereas quality controls for processed products have to do with production and processing and, thereby, a wider range of difficulties. Better raw materials for processed products come from strictly controlled production facilities that offer transparent agricultural production and a view toward export quality.

Then, we examine the heterogeneous effect of Green Food Certification on non-tariff barriers. In line with the WTO database, we regard agri-food products of the top 10 industries subject to SPS as products vulnerable to NTMs, including animal products, fruits, vegetables, dairy products, etc. These products are more likely to be affected by inputs such as chemical fertilizers, pesticides, veterinary drugs, feed, and additives in production, and comprise products likeliest affected by SPS and green barriers implemented by importing countries. Columns (3) and (4) of Table 9 show the results, especially the heterogeneous effects of Green Food Certification on products vulnerable to NTMs and other products. The coefficient of Green Food Certification is significantly positive for products vulnerable to non-tariff barriers, enough to show that Green Food Certification has a positive effect on breaking through trade barriers faced by agri-food products in ways consistent with work done by Martinez and Banados (2004).

Region heterogeneity To gain further insights into the effect of Green Food Certification on export quality, we focus attention on the development status of the importer. According to the UNSD (United Nations Statistics Division) classification standards for economies, we divide the destination markets into developed and developing regions. The results in columns (1) and (2) of Table 10 confirm that the positive impact of Green

Table 8 Endogenous test results[1)]

Variables[2)]	First Stage	Second stage
	Greenrate	*Exquality*
IV	–1.148***	
	(0.028)	
Greenrate		0.131***
		(0.050)
F statistic	293.90	
Kleibergen-Paap Wald F		1,721.574
Observations	310,133	310,133

[1)] Year, importer, and product fixed effects are included. Control variables are included. *Exquality*, export quality.
[2)] *Greenrate*, rate of Green Food Certification.
Robust standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

Table 9 Heterogeneous effects on different products

Variables[1)]	(1)	(2)	(3)	(4)
	Primary products	Processed products	Products vulnerable to NTMs[2)]	Other products
Greenrate	0.028**	0.007*	0.030***	0.005
	(0.011)	(0.004)	(0.011)	(0.004)
Control variables	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Importer fixed effects	Yes	Yes	Yes	Yes
Product fixed effects	Yes	Yes	Yes	Yes
Observations	135,018	175,115	132,061	178,072
R^2	0.134	0.088	0.133	0.089

[1)] *Greenrate*, rate of Green Food Certification.
[2)] NTMs, non-tariff measures.
Robust standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

Food Certification on the quality of products exported to developed regions is larger than that of developing countries and with a coefficient of greater statistical significance. This is because consumers in developed economies demand higher quality and demonstrate greater safety awareness in agri-food products, owing to their wealth and discretionary income. Also, as they have formed a more systematic inspection system for imported food, quality inspections tend to be strict compared to those among developing regions. As a result, Chinese exporters will more strictly abide by the Green Food standards and take the initiative to improve the export quality driven by profit. This reveals that, although developed countries often use high import standards as a trade protection measure to limit the export of agri-food products from developing countries, it also improves their export quality.

Moreover, importing countries impose varied standards due to income and technology gaps. Therefore, it is necessary to further explore domestic green certification impacts under varied importers' food quality standards. Since the differences in SPS measures reflect the level of importing regulation on agri-food quality, we define the top 10 countries in the notification of SPS measures announced by the WTO as regions with high agri-food quality standards (e.g., the United States, Brazil, Canada, the European Union, Japan, and Peru), others are regarded as regions with low standards of agri-food quality. The results in columns (3) and (4) of Table 10 demonstrate that Green Food Certification can improve the export quality for both regions, with greater efficacy in high-standard areas. The reason may be that when the standards of importing countries are higher, China's standards of Green Food Certification need to be coordinated upwards. In order to be in line with international standards, exporters have to be strict with food quality certification in production, processing, packaging, storage, etc. However, when the standards of importing countries are low, especially lower than those of China, the standards of Green Food Certification are coordinated downwards. Since the compliance cost of meeting the importing country's standard is almost zero, the impact of Green Food Certification on improving export quality is negligible.

Table 10 Heterogeneity analysis results on different regions

Variables[1)]	(1) Developed economies	(2) Developing economies	(3) High standards regions	(4) Low standards regions
Greenrate	0.018**	0.012*	0.022**	0.013**
	(0.008)	(0.006)	(0.009)	(0.006)
Control variables	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Importer fixed effects	Yes	Yes	Yes	Yes
Product fixed effects	Yes	Yes	Yes	Yes
Observations	97,576	199,215	84,310	225,813
R^2	0.189	0.138	0.214	0.131

1) Greenrate, rate of Green Food Certification.
Robust standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

3.5. Mechanisms test

As previously discussed, Green Food Certification can improve the export quality of agri-food products, with possible mechanisms including agricultural production efficiency and brand premiums. To test these channels, we regressed the mechanism variables on the main independent variable of the model (2). Table 11 shows the results of the mechanism test. Column (1) tests the impact of Green Food Certification on agricultural production efficiency, and the results show that the estimated coefficient is significantly positive, indicating that Green Food Certification improves agricultural production efficiency, consistent with Hypothesis 1. Column (2) presents the results of the brand premium as an intermediate channel. The results show that the effect of Green Food Certification is significantly positive, indicating that Green Food Certification can give Chinese exports and brands an advantage, which supports Hypothesis 2.

4. Discussion

Green Food Certification has a quality upgrading effect on the export of agri-food products, which provides new

Table 11 The results of the mechanism test[1)]

Variables[2)]	(1) TFP_{Kt}	(2) $Brand_{kt}$
Greenrate	0.011***	0.004***
	(0.003)	(0.001)
Control variables	Yes	Yes
Year fixed effects	Yes	Yes
Importer fixed effects	Yes	Yes
Product fixed effects	Yes	Yes
Observations	59,137	310,133
R^2	0.782	0.394

1) TFP_{Kt}, total factor productivity; $Brand_{kt}$, brand premiums.
2) *Greenrate*, rate of Green Food Certification.
Robust standard errors in parentheses. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

insights on nurturing new competitive advantages in agricultural trade and upgrading the global value chain in the context of high-quality trade development.

However, the degree of green certification in China's agri-food industry is still relatively low. The government can support standardized agricultural production in the form of establishing functional zones for Green Food production and standardized production bases, helping farmers to standardize their actions in agricultural production, streamlining inputs such as fertilizers and pesticides, and shifting from the traditional crude agricultural production mode to a precise and intensive one, so as to continuously bolster agricultural production. Simultaneously, the government helps enterprises to establish Green Food technology systems, forming multiple green and high-quality industrial chains from agricultural production to the processing, packaging, and transportation of agricultural products that finally reach foreign consumers. Our country should use Green Food labeling as a grip to distinguish agri-food products that are truly green and high quality from conventional products, build a market mechanism of high quality and good price, cultivate internationally competitive brands of agri-food products, and advance the value-added and international competitiveness of agri-food products for export.

Moreover, the level and technology of China's domestic agri-food standards certifications are far lower than those of developed countries, and green barriers such as SPS and TBT have become significant obstacles to agri-food export. Since China's WTO ascension, tariffs have been continuously reduced while NTMs have gained increasing prevalence. Chinese agri-food products have repeatedly been destroyed or returned due to pesticides or additives not meeting the food quality standards of importers. In the face of substantial non-tariff barriers to the export of agri-food products, Green Food Certification aims to provide green, high-quality agricultural products and effectively better the export quality of such products by regulating agricultural production practices and introducing advanced technologies. Our paper finds that China's exports to high-standard regions can contribute to strengthening domestic agri-food standards and regulations, which in turn raises overall export quality. Therefore, China should build its standards by staying abreast of advanced international standards to help it become a strong country with ever-improving standards and agri-food trade. At the same time, China can promote compliance, mutual recognition, and consistent assessment of agri-food standards among importing countries through free trade agreement negotiations to promote its agri-food standards throughout the international arena.

The empirical evidence in this paper reveals that China's Green Food Certification has positive implications for promoting high-quality agricultural exports. It also provides an empirical basis and reference for transforming and upgrading agricultural trade in other developing or emerging market countries.

5. Conclusion

Green Food Certification considers quality standards and environmentally sustainable development, which is an important starting point for promoting the green transformation of the agri-food system and the high-quality development of agricultural trade. This paper studies the effect of the Green Food Certification on the export quality of agri-food products using export data from about 603 agri-food products from China to 162 importing countries or regions during 2006–2020 and then explores the impact mechanisms. Our most notable findings are as follows. First, we find evidence suggesting that Green Food Certification can improve the export quality of agri-food products. Our conclusions remain robust to different specifications, including replacing indicators, adjusting the sample period, and considering omitted variables and endogeneity. Second, the results of heterogeneity analysis show that, among various products, Green Food Certification has a greater effect on the export quality of primary products and agri-food products that are vulnerable to non-tariff barriers. In terms of region heterogeneity, the quality-enhancing effect of Green Food Certification is more pronounced for exports to developed regions and regions with high agri-food quality standards. Third, further mechanism checks reveal that this improved effect is mainly due to enhancing agricultural productivity and forming brand premiums. The above conclusions provide important implications for guiding the green transformation of agri-food systems and the high-quality development of agricultural trade.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (72061147002) and the National Social Science Foundation of China (18ZDA074). We also thank Dr. Zhuang Wang and Ph.D. candidate Xixi Li for their help in collecting data.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Appendix associated with this paper is available on https://doi.org/10.1016/j.jia.2023.11.033

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