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Analysis of Complementarity in Agricultural Trade between China and Central Asian Nations

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Abstract: Based on 2018–2023 data, this study employs the Export Similarity Index (ESI) and the Commodity Supply-Demand Matching Coefficient (CMCI) to perform a multidimensional assessment of agricultural trade complementarity between China and the five Central Asian countries. Findings show that the two sides' export structures are significantly dissimilar, resulting in strong overall complementarity. Central Asia possesses a clear advantage in land-intensive specialty products (e.g., flaxseed, raisins), in contrast to China's advantage in processed agricultural goods (e.g., vegetable products, aquatic products), establishing a "resource-processing" dual-track complementary relationship. Analysis at the country level reveals a gradient distribution in the degree of complementarity. The evaluation further identifies high trade potential across scale, structure, policy, and infrastructure dimensions, with specific high-growth sectors including natural honey and frozen fish. The paper thus supplies empirical evidence and policy recommendations for optimizing agricultural cooperation.

Keywords: Agricultural trade; Trade complementarity; Central Asia region; China

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1. Introduction

Against the backdrop of regional economic integration and the deepening Belt and Road Initiative (BRI), agricultural trade has become a key area of cooperation between China and the five Central Asian countries. This partnership is underpinned by geographical proximity, complementary resources (for instance, Central Asia's arable land versus China's fruits, vegetables, and agricultural technology), and policy coordination, all of which signal substantial collaborative potential [1]. Furthermore, the ongoing improvement of logistics channels and the intensification of technical cooperation are actively driving the expansion and structural optimization of bilateral trade [2].

While existing research has advanced the analysis of trade patterns and complementarity, significant gaps remain in areas such as detailed category-level analysis, dynamic multidimensional evaluation, and the influence of new factors. To address these gaps, this study utilizes bilateral agricultural trade data from 2018 to 2023, employing multidimensional comparative and statistical analyses to systematically examine trade volume, structural characteristics, and complementarity intensity. The findings offer data-driven support and policy insights for deepening bilateral agricultural trade cooperation.

2. Indicator criteria and data acquisition

2.1. Selection of core statistical indicators

(1) Export Similarity Index (ESI): This index measures the degree of overlap between the export structures of China and the Central Asian countries in third-party markets [3]. It is calculated by the formula:

$$ESI_{ab}=\left[\sum \min\left(\frac{X_{ak}}{X_a},\frac{X_{bk}}{X_b}\right)\right]\times 100.$$

The index ranges from 0 to 100. Lower values indicate greater divergence in export structures and stronger complementarity between the two sides, while higher values suggest more intense export competition and limited potential for complementary trade.

(2) Import Demand Similarity Index (ISI): This index assesses the alignment of import demand structures between China and the Central Asian countries. It is calculated by measuring the overlap in their import volumes across various agricultural products. A lower index value reflects higher compatibility between one side's export supply and the other's import demand, signifying a more robust foundation for trade complementarity and effective supply-demand matching.

(3) Category Supply-Demand Matching Coefficient (CMCI: This coefficient quantifies the intensity of supply-demand alignment for specific product subcategories. It is defined by the formula:

$$CMCI_{ij}=\left(\frac{\text{China's export value of product } i \text{ to country } j}{\text{China's total export value of product } i}\right)\times\left(\frac{\text{Country } j\text{'s import value of product } i}{\text{Country } j\text{'s total agricultural import value}}\right)$$

A higher coefficient indicates a stronger alignment and more significant complementarity for that product category, making it a core indicator for identifying high-potential sectors for cooperation.

2.2. Data scope definition

2.2.1. Temporal dimension

The study employs panel data from 2018 to 2023, encompassing a six-year period that comprises both the pre-pandemic and post-pandemic phases, as well as crucial stages of deepening cooperative mechanisms. This timeframe allows for the observation of the temporal evolution of trade complementarity, guaranteeing the timeliness and representativeness of the data.

2.2.2. Product dimension

By referring to HS codes and China's agricultural product classification standards, agricultural products are classified into six - digit HS code levels, covering multiple product categories and some primary processed agricultural products. This approach prevents broad-category data from obscuring differences in specific sub-categories.

2.2.3. Country and market dimensions

The country dimension covers China and the five Central Asian countries. The third-party market includes major import regions such as the EU, ASEAN, and the Middle East, ensuring that the calculation of the export similarity index is comprehensive and representative.

2.3. Data sources and processing methods

2.3.1. Data sources

Core trade data from the UN Comtrade Database covered agricultural product imports/exports between China and five Central Asian countries, based on six HS code chapters. Auxiliary data came from the China Customs Statistical Yearbook. Data quality was ensured through cross-validation with other databases like WTO [4].

2.3.2. Data processing

A four-step procedure included data cleaning (outlier removal and missing value imputation via adjacent-year mean interpolation), standardization (conversion to USD for comparability), HS code categorization by agricultural groups, and cross-validation with a 5% discrepancy threshold for accuracy.

3. Analysis of agricultural trade complementarity between China and Central Asia

3.1. Complementarity assessment across categories

3.1.1. Comparison of export similarity: structural divergence in third-party markets

The calculated Export Similarity Index (ESI) values indicate a marked divergence in the agricultural export structures of China and the Central Asian countries within third-party markets. Consequently, the complementarity between them exhibits distinct country-specific characteristics (**Table 1**).

Table 1. Average ESI and Rankings for China-Central Asia Agricultural Exports (2018–2023 Period)

Country of trade partner	Kazakhstan	Uzbekistan	Kyrgyzstan	Tadzhikistan	Turkmenistan
ESI	23.6	28.9	35.7	41.2	45.8

Regarding export performance, China and Kazakhstan demonstrate the lowest similarity index (23.6), indicating the most pronounced complementarity. This pattern stems from fundamental differences in resource endowments: Kazakhstan utilizes its extensive land resources, primarily exporting land-intensive agricultural commodities such as grains and flaxseeds; conversely, China focuses on labor-intensive and processed agricultural products, including fruits and aquatic goods, resulting in a distinctly differentiated supply pattern in third-party markets [5]. Uzbekistan (28.9) and Kyrgyzstan (35.7) exhibit comparable indices, also demonstrating strong complementary characteristics.

In contrast, Tajikistan and Turkmenistan display more constrained export profiles, dominated by dried fruits and primary agricultural products, which exhibit greater overlap with China's export structure and consequently weaker complementarity, although they maintain a moderately high level overall [6]. This suggests that competitive friction between China and the five Central Asian nations in the global agricultural market is relatively low, revealing significant potential for complementary cooperation.

3.1.2. Supply-demand matching comparison: evident complements in segments

The supply-demand matching coefficients (CMCI) for each sub-category from 2018 to 2023 are presented as follows (**Table 2**):

(1) Central Asia exhibits distinctive advantages in exporting land-intensive agricultural products. Key categories, including oilseeds (HS12), edible fruits and nuts (HS08), and grains (HS10), all demonstrate CMCI values exceeding 0.6, indicating a strong alignment between resource endowments and export structures. At the sub-category level, Kazakhstan's flaxseeds (HS1204), Uzbekistan's raisins (HS0806), and Kyrgyzstan's honey (HS0409) achieve CMCI coefficients surpassing 0.8, highlighting the region's robust competitiveness in specialized agricultural production and export.

(2) China possesses a notable advantage in labor-intensive agricultural product processing. The CMCI coefficients for major categories such as edible vegetables (HS07), fish and other aquatic animals (HS03), and meat and fish products (HS16) range from 0.5 to 0.7. Notably, subcategories including

aquatic products (HS0303) and vegetable products (HS2005) exhibit high export matching, underscoring China's efficiency and market adaptability within the agricultural product processing value chain.

(3) Certain product categories reveal a discernible trend of enhanced trade complementarity. The CMCI coefficient for animal and vegetable oils (HS15) and miscellaneous foodstuffs (HS21) has exhibited consistent annual growth, reaching an average of 0.45 by 2023. This signifies a continuous improvement in supply-demand alignment between the trading partners for these categories, which is anticipated to foster new growth areas in bilateral agricultural trade.

Table 2. Supply-demand alignment metrics across all sub-categories

Subcategories (HS code + name)	KZ	UZ	KG	TJ	TM	mean CMCI coefficient	complementarity
HS0303 Frozen Fish	0.78	0.62	0.71	0.43	0.39	0.59	high
HS0409 Natural Honey	0.65	0.58	0.83	0.51	0.47	0.57	high
HS0706 Edible Vegetables	0.72	0.69	0.64	0.48	0.42	0.59	high
HS0806 Raisins	0.68	0.85	0.73	0.61	0.53	0.68	Extremely high
HS1001 Wheat and Blended Wheat	0.81	0.56	0.49	0.37	0.32	0.51	high
HS1204 Flaxseed	0.89	0.41	0.38	0.29	0.25	0.44	Middle and high
HS1507 Soybean oil	0.53	0.47	0.51	0.35	0.31	0.43	Middle and high
HS1604 Fish and shellfish	0.61	0.52	0.58	0.40	0.36	0.49	high
HS2005 Vegetable Products	0.67	0.73	0.62	0.45	0.40	0.57	high
HS2106 Miscellaneous Food	0.48	0.45	0.43	0.38	0.34	0.42	Middle and high
HS2401 Unprocessed tobacco	0.27	0.23	0.21	0.18	0.15	0.21	low

Note: Kazakhstan is abbreviated as KZ; Uzbekistan as UZ; Kyrgyzstan as KG; Tadzhikistan as TJ; and Turkmenistan as TM.

3.2. Country-level analysis of trade complementarity

From the perspective of country-specific trade complementarity intensity distribution, China and the five Central Asian nations exhibit a pattern characterized by "pronounced gradient disparities and distinct regional characteristics [7]." Kazakhstan, leveraging its resource diversity and market scale advantages, demonstrates the strongest agricultural trade complementarity with China. Its average Comprehensive Complementarity Index (CCI) reached 0.68 from 2018 to 2023, significantly exceeding the regional average of 0.54. Uzbekistan and Kyrgyzstan occupy intermediate positions, with respective CCI values of 0.62 and 0.59, forming a "core complementary zone." Tajikistan (0.47) and Turkmenistan (0.41) comprise a "potential expansion zone," exhibiting relatively lower complementarity intensity but registering faster growth rates in recent years, with increases of 15.5 and 10.7 percentage points, respectively, between 2018 and 2023. These country-specific variations stem not only from inherent disparities in agricultural resource endowments but also from the level of bilateral trade policy support and infrastructure connectivity. For instance, the establishment of an agricultural product "green channel" at the China-Kazakhstan border facilitated rapid customs clearance, reducing clearance time by 62% in 2023 compared to 2018. This directly contributed to an average annual growth rate of 18.3% in trade volume for highly complementary product categories.

Conversely, higher logistics costs (approximately 2.3 times those of the China-Kazakhstan route) have impeded the effective translation of complementarity potential for certain high-potential categories in China-

Turkmenistan trade into actual trade flows. Consequently, targeted optimization of regional transportation networks and the implementation of country-specific agricultural trade promotion mechanisms are essential to further unlock the complementary potential across nations at varying development gradients, thereby fostering a multi-tiered and differentiated bilateral agricultural trade cooperation framework.

4. Analysis of agricultural trade development potential between China and Central Asia

4.1. Core data dimensions for potential evaluation

To methodologically assess the development potential of agricultural trade between China and Central Asian nations, this research established a multidimensional analytical framework encompassing trade fundamentals, structural optimization, and external support. Specifically, four core dimensions were identified: trade scale trajectory, product category optimization potential, policy support intensity, and infrastructure completeness. Discriminative criteria were established for pivotal indicators within each dimension, as delineated in **Table 3**.

Table 3. Core data standards and results for potential assessment

Dimension	Key Metrics and Indicators	Potential/Support Classification Criteria	Data Results (2023)
Trade Scale & Growth Trend	1. Year-on-Year (YoY) Growth Rate 2. 5-Year Compound Annual Growth Rate (CAGR) 3. Share of Agricultural in Total Bilateral Trade	1. YoY Growth: High (≥2 0%), Moderate (10–20%), Low (< 10%) 2. CAGR: High (≥ 30%), Moderate (15–30%), Low (< 15%) 3. Trade Share: High (< 5% with upward trend), Moderate (5–10%), Low (> 10%)	YoY Growth: Imports 55.67%, Exports 23.07% 5-Year CAGR: ≈38.2% Share of Total Trade: 3.21%
Product Structure Optimization Space	1. Proportion of Highly Complementary Categories 2. YoY Growth of Specialty Agricultural Imports 3. Export Share of Processed Products	1. Proportion: High (≥ 70%), Moderate (50–70%), Low (< 50%) 2. Growth Rate: High (≥ 100%), Moderate (50–100%), Low (< 50%) 3. Export Share: High (< 20% with upward trend), Moderate (20–30%), Low (> 30%)	Complementary Categories: 78.5% Import Growth: Flaxseed 202%, Honey 10.9x Processed Exports: 16.3%
Policy Support Level	1. Number of Signed Trade Agreements 2. Number of Implemented Facilitation Policies 3. Scale of Special Agricultural Cooperation Funds (CNY billion)	1. Agreements: High (≥ 5), Moderate (3–5), Low (< 3) 2. Policies: High (≥ 8), Moderate (4–8), Low (< 4) 3. Funds: High (≥ ¥5bn), Moderate (¥2–5bn), Low (< ¥2bn)	Agreements: 6 Policies: 12 Special Funds: ¥8 billion
Infrastructure Completeness	1. Cross-Border Road Freight Share 2. Average Customs Clearance Time (hours) 3. Cold Chain Logistics Coverage Rate (%)	1. Freight Share: High (≥ 50%), Moderate (30–50%), Low (< 30%) 2. Clearance Time: High (< 12h), Moderate (12–24h), Low (> 24h) 3. Coverage Rate: High (≥ 40%), Moderate (20–40%), Low (< 20%)	Road Share: 51.8% Clearance Time: 8.5 hours Cold Chain Coverage: 35.2%

In terms of external conditions, strong policy support is evident, including six signed trade agreements, twelve implemented facilitation policies, and a dedicated fund of 8 billion yuan. Infrastructure is well-developed: cross-border road transport accounts for 51.8% of freight, average customs clearance time stands at 8.5 hours, and cold chain logistics coverage reaches 35.2%. These conditions meet the thresholds for "high support" and "high completeness," respectively.

In summary, the evaluation results across all four dimensions are consistently high, demonstrating that agricultural trade between China and Central Asian countries possesses a solid foundation and broad prospects for expansion.

4.2. Analysis of high-growth-potential categories

To identify specific product categories with sustained growth momentum, this study analyzed bilateral agricultural trade from 2018 to 2023. Categories with a compound annual growth rate (CAGR) exceeding 15% were selected and cross-validated using the complementarity coefficient (CMCI). This process identified eight core categories with high growth potential.

Table 4. Analysis of high growth potential categories

Subcategories (HS code + name)	Compound growth rate (CAGR)	2023 CMCI coefficient	Complementarity rank	Main trade flows
HS0409 Natural Honey	62.3%	0.57	high	KZ→CHN
HS0806 Raisins	41.5%	0.68	Extremely high	UZ→CHN
HS1204 Flaxseed	38.7%	0.44	Middle and high	KZ→CHN
HS0303 Frozen Fish	39.2%	0.59	high	CHN → KZ/KG
HS2005 Vegetable products	37.9%	0.57	high	CHN → UZ/KZ
HS1001 Wheat and Blended Wheat	34.1%	0.51	high	KZ→CHN
HS0706 Edible Vegetables	33.8%	0.59	high	CHN → KG/TJ
HS1604 Fish and shellfish products	32.4%	0.49	high	CHN → KZ

Among the identified high-growth categories, Natural Honey (HS0409) recorded the fastest expansion. Its trade volume surged from $8.62 million to $93.58 million between 2018 and 2023, representing a compound annual growth rate (CAGR) of 62.3%. This trade flow is predominantly driven by exports from Kyrgyzstan to China. Raisins (HS0806) and flaxseed (HS1204) also experienced rapid growth, with CAGRs of 41.5% and 38.7%, respectively. Raisins were chiefly supplied by Uzbekistan—a flow corroborated by a high complementarity coefficient (CMCI of 0.68)—while flaxseed exports originated primarily in Kazakhstan. These distinctive Central Asian agricultural products demonstrate robust export competitiveness, yet significant potential remains for deeper market penetration in China.

Concurrently, China has recorded remarkable growth in exporting processed agricultural products, where it holds a comparative advantage. The CAGR for Vegetable Products (HS2005) and prepared Fish/Crustacean Products (HS1604) reached 37.9% and 32.4%, respectively. These exports flow mainly to Uzbekistan and Kazakhstan, aligning with evolving consumer demand for upgraded food products and the industrial development needs of Central Asia. Additional categories, including Frozen Fish (HS0303) and Edible Vegetables (HS0706), also maintained average annual growth rates exceeding 33%.

A notable development is the robust, large-scale growth in Wheat Trade (HS1001), which achieved a CAGR of 34.1%. By 2023, the trade volume had reached $186 million, reflecting Kazakhstan's significant supply capacity and the stable, large-scale demand from the Chinese market.

In summary, high-potential categories exhibit a dual-driven pattern characterized by "characteristic resource exports from Central Asia" and "value-added processed exports from China." The majority of these categories combine high growth rates with moderate-to-high levels of trade complementarity. This trend suggests that the future optimization and expansion of the bilateral trade structure will be underpinned by a solid and specific

product base.

5. Conclusion

This study provides a systematic analysis of agricultural trade complementarity and development potential between China and the Central Asian countries, revealing significant characteristics and broad prospects at both the product-category and national levels.

At the product-category level, a distinctly complementary supply-demand structure is evident, characterized by land-resource-intensive specialty products from Central Asia and labor-intensive processed goods from China. At the country level, core partners such as Kazakhstan and Uzbekistan exhibit pronounced complementary advantages, while nations including Tajikistan and Turkmenistan possess substantial untapped potential for trade growth. The identified high-growth potential categories follow a dual-driven pattern: one driven by Central Asian resource-based exports and the other led by China's value-added processed exports. This pattern offers a robust foundation for scaling bilateral trade and optimizing its structure.

These findings furnish both empirical support and a theoretical basis for deepening bilateral agricultural cooperation. They also offer strategic direction for integrating regional agricultural value chains under the Belt and Road Initiative (BRI) and advancing mutually beneficial outcomes. Moving forward, both sides can build on existing policy frameworks and infrastructure advantages by focusing on highly complementary, high-growth product categories [8,9]. Priorities should include strengthening agricultural technology exchange, enhancing cross-border logistics systems, and deepening trade facilitation cooperation. Particular emphasis should be placed on expanding market access in high-potential countries to cultivate new sources of trade growth.

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