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RESEARCH ARTICLE

Unlocking the export potential of Indian millets for global food security

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Abstract

Millets are gaining renewed importance in India due to their nutritional richness and ability to thrive in adverse climatic environments. This study evaluates the export performance of three major millets: ragi (finger millet), bajra (pearl millet) and jowar (sorghum) using exports as a key indicator. Export data from 2014 to 2024 was analysed using two primary methods: the Compound Annual Growth Rate (CAGR), to assess year-on-year growth in export value and quantity and Markov chain analysis, to examine the evolution of trading relationships with importing countries. The findings indicate that bajra showed the most consistent progress in both export value and volume. Ragi experienced a slight decline in volume but a significant increase in value, likely due to higher unit prices or value-added product exports. Jowar, despite having the lowest volume, recorded the highest increase in export value, reflecting emerging but uncertain demand. The most stable importing countries were identified as Saudi Arabia, Nepal and Libya. Overall, the results suggest that India has strong potential to enhance millet exports by expanding value-added offerings, entering new markets and strengthening trade relationships with key importers.

Keywords: export trends; finger millet; pearl millet; sorghum; trade direction

Introduction

Millets are a group of many small dryland cereal grain crops which include pearl, proso, foxtail, barnyard, little, kodo, brown top, finger and guinea millets, black and white fonio, sorghum, teff and Job's tears and many more varied and local species (1). Millets are often referred to as “nutrient-rich grains” and grow very well in soils that are poor and have low fertility. The term millet is said to be derived from a French word *mille*, which means ‘thousand’, presumably referring to the number of seeds in a small amount (2). In the developing world, millets are staple foods, especially in drylands of Africa and Asia. Most of the millets are native to Africa and were domesticated to other regions later. Millets are grown in 93 counties around the world and only 7 countries grow more than 1 million hectares of acreage of millets (3).

Millets are widely grown and play a crucial role in traditional diets and behaviours around the world, especially in India and Sub-Saharan Africa (1). Though they are among the first crops domesticated as agriculture began, millets are very poorly known and the importance they provide with respect to food security and the contribution that millets provide to local cultural systems is often ignored. Millets have excellent nutritional value because they are rich in calcium, iron, potassium, magnesium and zinc, among other vitamins, amino acids and fatty acids (4). Millets have additional attributes for consumers today; as a gluten-free protein, high fibre food and low glycaemic index food. Millets are trending upward because of their tolerance to water stress, high temperatures and low-fertility soils - environments to which millets can thrive. Millets are increasingly being cultivated and consumed due to their health benefits and their significance in both health and industrial applications is steadily growing. Millets have been cultivated in East Asia for over 10000 years. Millets have long served as staple crops in millets semi-arid areas of Asia and Africa and relied by millions of low-income households for the primary energy, protein, vitamins and minerals in their diets (5). The key millets cultivated in India include pearl millet (bajra), sorghum (jowar), finger millet (ragi), foxtail millet and little millet. India features many collection sites for millets. The major states for millet production are Rajasthan, Uttar Pradesh, Haryana, Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh and Telangana. Together the above 10 states account for approximately 98 % of all millet production in India (6). Millets are very appealing in India given they are a nutrient-rich food and ostensibly have a prominent role to play in India's food security initiatives. Millets are garnering world-wide attention and there is also considerable consumer focus on the search for healthier and more sustainable food products. Thus, it is imperative to maintain this focus through further building larger markets and developing promotional awareness. This marketing can include advertising campaigns, ensuring consumer

awareness and education and lastly providing farmers with training and information around growing and consuming millets. With proper support and promotional initiatives, millets can also substantially enhance India's nutrition, public health and environmentally sustainable agriculture (7). The government aims to showcase millets as safe, nutritious cereals that benefit both people and the planet. By promoting the production of ready-to-eat and ready-to-cook millet products that cater to global tastes and meet international quality standards, it seeks to boost their acceptance in export markets (6).

As per Food and Agriculture Organization (FAO), India accounts for 17 % of global area under millet and 18 % of global millet production. Export demand for millets will come from consumption patterns that exist in the importing country. While millets have significant importance for people in the arid and semi -arid regions of Asia and Africa (for both carbohydrates and proteins), it is also used as an animal feed in most of the developed countries (8). In 2022, India produced a total of 165 lakh tonnes of millet, across 121 lakh hectares. India has also made some policy decisions to facilitate preservation of millet. India referred millet crops as 'NutriCereals', in addition to declaring year 2018 as the 'National Year of Millets' to emphasis the unique characteristics of millets. Furthermore, India is one of the top five export countries for millet globally. Exports of millet increased from $400 million in 2020 to $470 million in 2021 as per ITC trade map. During 2021-22 India exported millets of $64.28 million compared to $59.75 million in 2020-21. The percentage of value-added products based on millet is very low. India as the number one producer and exporter of grains in the world, exported ₹96011.42 crore / $12872.64 million worth of grains in 2021-22. During the same year, 75 % (in value terms) of the cereal exports in India (including basmati and non-basmati) were rice. Thus, millets remain in their primary form (feeds or industrial purposes). There is a strong potential for commercialization of millets towards food-based management of this health challenge (9).

India presently has less than 2 % of the worldwide millet market, despite being the largest millet producing country. The size of the millets market is expected to grow to over $14 billion based on increased global markets demand, with a CAGR of 4.6 % from 2019-2027 (10). The Asia-Pacific region has the largest market share at 40.9 %, followed by the Middle East at 32 % and Europe with 14.1 %. Given this, India must improve exports and global market integration to meet these demands. Thus, we will focus our practice in millet on export trends and the prospects for unlocking export opportunities. The objectives of the study are to examine the export trends of major Indian millets-finger millet, pearl millet and sorghum-over the period 2014-2024; to analyse the structural changes in the export destinations of Indian millets using Markov chain analysis, thereby identifying trade direction, consistency and market dependency; and to estimate the growth performance of millet exports from India using the CAGR method.

Materials and Methods

Among the various coarse cereals cultivated in India, ragi or finger millet, bajra or pearl millet, jowar or sorghum were selected for the study, based on their nutritional importance, drought tolerance and increased global demand. These crops are the most important cereals of dryland agriculture in India and have considerable export development potential. The study aimed to determine the export trends and trade pattern of the selected millets from India. Port-wise export data on ragi, bajra and jowar, were obtained from the Agricultural and Processed Food Products Export Development Authority for the period of 2014–2024 (11). Area, production and productivity data is collected from Indiastat from 2014-2025 based on the date availability into consideration. Export trends were analysed with CAGR and the structural changes in trade were analysed with Markov Chain transition probability models.

CAGR

The rates of growth in export value and quantity were derived from an exponential growth function.

$$Y_{it}=A_i(1+r_i)^t \qquad \text{(Eqn.1)}$$

This is used to provide the compound growth rate analysis.

Where,

Y_{it} - Export quantity/value of i^{th} crop (jowar, ragi, bajra) in time t

r - Compound growth rate of Y_i

A_i - Initial year export quantity/value of i^{th} crop

t - time in years

Taking the natural logarithm of (Eqn.1)

$$\text{Ln } Y_{it}=ai+\beta_i t+U_i \qquad \text{(Eqn.2)}$$

Y_{it}= Export quantity/value of i^{th} crop in time t

t = time in years in the log linear function was estimated.

The compound growth rate (r) was found using

$$r_i=(\text{Antilog } \beta_i\text{-}1)\times 100$$

$$r_i=(\text{Antilog } \beta_i\text{-}1)\times 100 \qquad \text{(Eqn.3)}$$

Markov chain analysis

Markov chain analysis was employed to estimate the transitional probabilities of Indian millet exports across various international markets, thereby identifying how the direction of trade evolves over time. This approach captures the dynamic nature of global trade by analysing year on year shifts in major importing countries, enabling researchers to assess the degree of market stability and dependency. Through this, the analysis provides valuable insights into the consistency and diversification of India's export portfolio.

The structural change in any system where evolution α = a constant term and β = regression co-efficient and we will call it a year-on-year Ordinary Least Square (OLS) approach specific to a single outcome variable, which in our case we described (SP) using Markov chain analysis. In this paper we ran a Markov chain model with an aim at analysing the trade flows and structural change for Indian ragi, bajra and sorghum (12). In our Markov chain we first generated a transitional probability matrix (P) and the elements P_{ij} represent the probability that the exports transition from country "i" to country "j". We measure the probability that a country maintained their market share or alternatively, how committed the importing country is to a particular exporting country through a diagonal element P_{ij} when i=j. In our case of nine cereal importing nations, we treated structural change as a random and allowed our experimental design to test different parameters.

Where,

$E_{jt} = \text{Export from } E_{jt}=\sum_{i=1}^{r} E_{it-1}P_{ij}+e_{jt} \text{ India to the } j^{th} \text{ country in year } t$

E_{it-1} = Export to i^{th} country in year t-1

P_{ij} = the Probability that exports will shift from the i^{th} country to j^{th} country

e_{jt} = the error term which is statically independent from E_{it-1}

n = number of importing countries

The transitional probabilities P_{ij}, which can organized into a (c × r) matrix, have the properties

$0 < P_{ij} < 1 = 1$ for all i

All exports of grains to these countries in the previous period is multiplied by the transitional probability matrix to obtain the predicted share of each importing country in period "t."

Results and Discussion

Millets are known for their high nutritional density, being rich in dietary fibre, essential amino acids, antioxidants and bioactive compounds. According to the National Institute of Nutrition (NIN), finger millet (ragi) contains the highest calcium content (344 mg/100 g) among cereals, which supports bone health, while pearl millet (bajra) is rich in iron and zinc, vital for immunity and anaemia prevention. Sorghum (jowar) is notable for its polyphenols and anti-inflammatory properties, contributing to the management of diabetes, cardiovascular disease and obesity (13). Millets have a low glycemic index, making them ideal for diabetic diets (14). Moreover, millets are gluten-free, making them a suitable alternative for individuals with celiac disease and gluten intolerance. Recognizing these functional health properties aligns well with global food security strategies by promoting preventive nutrition and dietary diversity, especially in low- and middle-income countries where non-communicable diseases are rising (15).

The Indian millet sector has shown mixed growth trends, with bajra recording a 15.10 % CAGR in production and 26.72 % CAGR in productivity between TE 1968–69 and TE 2022-23, while jowar and ragi saw negative growth in production at -16.26 % and -1.83 % respectively. Despite area under cultivation declining significantly, productivity gains helped offset losses in bajra and ragi. India's millet export quantity rose by 29.56 % in 2022-23 over the previous year, with total exports valued at $75.43 million. Globally, the millet market is projected to grow from $11.02 billion in 2023 to $13.80 billion by 2028, at a CAGR of 4.6 %. This growth rates reflect renewed global and domestic interest, driven by nutrition awareness, policy support and sustainable food demand. Therefore, recent trends suggest a revival in millet trade with strong export potential for India.

CAGR analysis

In the year 2014-2024, the average annual export volume of ragi stood at 61149 MT with an average export value of ₹160.7 crores (Table 1). The average export volume of bajra was around 52723 MT, with an average export value of ₹136.6 crores. The average export volume of jowar was much lower, at around 1269 MT with an average export value of ₹4.7 crores. The export of ragi showed large fluctuations from year to year, with a high Coefficient of Variation (CV) of 59.63 % for quantity and even more extraordinary 74.10 % for value, which denotes a highly unstable trading pattern. On the contrary, the quantity and value of bajra were more stable, but still with a high CV (19.69 % for quantity and 29.91 % for value). Jowar showed very high volatility with the coefficients of variation extremely high to the point of inferring displays very irregular and unstable trading patterns (76.15 % for quantity and 91.08 % for value).

The export quantity CAGR for ragi is -0.75 % revealing a declining trend, but the export value CAGR is 5.08 %, with this indicative of increases in value realization per unit quantity and/or more value added exports. Bajra has positive CAGR for both quantity (1.82 %) and value (5.10 %), representing a healthy export performance with continued growth. Jowar has a very small volume but also has positive CAGR for both quantity (0.92 %) and value (8.08 %) but with value moving faster than quantity.

The study shows ragi is challenged to hold steady at quantity but has been able to improve on value. Bajra is the most consistent and stable emerging export, while jowar is very low volume but very volatile, but shows positive value growth. Importantly, it illustrates many ways in which Indian coarse cereals can positively impact export performance, through varied exporting destination markets, potential opportunities for value added processing and assured supply of products for export.

Markov chain analysis

Jowar

Sorghum, well-known as Jowar is India's major millet. In the year 2021-22, it was produced nearly 4 million tonnes and the average yield was 1.1 tonnes per hectare. That year, sorghum was cultivated on nearly 15.5 million hectares of land (16).

The transitions of jowar (sorghum) import/export dynamics from India were studied using a transitional probability matrix provided in Table 2. The significant importing countries are as listed: UAE, Saudi Arabia, Libya, Oman, Tunisia, Yemen, Qatar, UK and Morocco. Libya preserved 77.44 % of its original share, which represents a strong and consistent import portfolio relationship with India. The UAE preserved only 10.44 % of its share and here too, a large amount of its share was directed and shifted to other countries, mainly Libya (18.95 %), Saudi Arabia (20.69 %), Oman (10.75 %) and Tunisia (9.79 %). Morocco preserved 19.58 % of its share and directed significant portions to Libya (25.96), Saudi Arabia (23.56) and Oman (18.27), which indicates a diversifying shift to the other Middle East nations. Saudi Arabia entirely shifted its share to UAE, while Omen, Tunisia, Yemen, Qatar and UK display a complete transition of their shares to UAE, indicating a limited or diminishing role as direct importers. The UK redirected only 6.81

Table 1. Coefficient of variation and growth analysis for the export of selected commodities

S.No	Commodities	Mean		Standard Deviation		Coefficient of Variation		Compound Annual Growth Rate	
		Export quantity (in metric tonnes)	Export value (in crores)	Export quantity	Export value	Export quantity	Export value	Export quantity	Export value
1	Ragi	61149.1	160.7	3646.2	11.9	59.63 %	74.10 %	-0.75 %	5.08 %
2	Bajra	52723.0	136.6	10378.6	40.9	19.69 %	29.91 %	1.82 %	5.10 %
3	Jowar	1269.4	4.7	966.7	4.3	76.15 %	91.08 %	0.92 %	8.08 %

Table 2. Transition probability matrix for the export of jowar

Country	UAE	Saudi Arabia	Libya	Oman	Tunisia	Yemen	Qatar	UK	Morocco
UAE	0.1044	0.206924	0.189503	0.107542	0.097954	0.085858	0.08153	0.068128	0.058161
Saudi Arabia	1	0	0	0	0	0	0	0	0
Libya	0.77441	0.106085	0.070811	0.038314	0	0	0	0	0.01038
Oman	1	0	0	0	0	0	0	0	0
Tunisia	1	0	0	0	0	0	0	0	0
Yemen	1	0	0	0	0	0	0	0	0
Qatar	1	0	0	0	0	0	0	0	0
UK	1	0	0	0	0	0	0	0	0
Morocco	0.040224	0.235625	0.259856	0.182661	0.085767	0	0	0	0.195867

% from the share of UAE and showed limited activity otherwise of direct transitions. Yemen and Qatar displayed slight retention or activity with no retention or inflows during the study.

The results indicate that currently Libya, UAE and Morocco are the most stable and active markets for Indian jowar exports. Libya is the most committed with a minimal variation followed by Morocco who is showing moderate retention and redistribution. Countries like Saudi Arabia, Oman and the UK show all switch activity indicating a fair amount of less stability in terms of trade.

Ragi

Finger millet (also known as ragi), is one of the main millets grown in India, primarily produced in the South Indian states and Uttarakhand. In 2021-22, the area planted with finger millet was approximately 1.2 million hectares and the production level was close to 1.7 million tonnes (with an average yield of around 1.4 tonnes per hectare (16)).

The flow of ragi exports from India was analysed using a transition probability matrix, as illustrated in Table 3. Some major importing countries consist of Nepal, UAE, Malaysia, USA, Qatar, Maldives, Canada, Kuwait and the UK. Nepal would appear to be the most stable and loyal importing country, retaining around 95.96 % of its original export percentage share from India; only a fraction of its market share was diverted to UAE (2.51 %), Malaysia (0.32 %) and USA (0.29 %), which thus highlighted Nepal's stable market status for ragi over the years. UAE retained about 56.49 % of its original percentage share of imports from India; the balance of its original share was diverted to other importing countries, with a sizable share of the diverted share going to Malaysia (12.60 %), USA (6.80 %) and Qatar (2.86 %). There was also a small share shifted to Maldives, Canada, Kuwait and the UK, which would indicate that there was a moderate stability with market share; however, the movement of share did occur. In contrast, Malaysia, USA, Qatar, Maldives, Canada, Kuwait and the UK did not retain any of their share within other importing markets, but rather transferred all of their share to Nepal or UAE, which may indicate either a withdrawal from the marketplace or as a consequence of re-exporting more competently from dominant importing countries such as Nepal or UAE.

From this analysis, Nepal is a prospective market for Indian ragi exports and it appears to provide consistent potential. The UAE also provides some value but remains more volatile than Nepal. Other countries do seem to offer distorted participation in direct imports or uncertainty and could be secondary markets departing or developing long-term prospects.

Bajra

Commonly known as bajra, pearl millet is the second most widely cultivated millet in India. During the period of the year 2021-22, it was grown on an estimated area of about 6.8 million hectares yielding nearly 10 million tonnes. The projected average yield for bajra was about 1.4 tonnes per hectare (16).

The transition probability matrix illustrates the changes in bajra exports from India with consideration of various importing countries - UAE, Saudi Arabia, Libya, Oman, Tunisia, Yemen, Qatar, UK and Morocco (Table 4). Saudi Arabia is the most dominant and largest importer and plays an integral role in the global bajra export market, almost maintaining its 94.51 % original share of bajra exports from India. Saudi Arabia shifted small portions (5.49 %) of its original bajra export share to Libya, which affected the redistribution of Bajra exports. Saudi Arabia also received its most significant share from the UAE (57.91 %). The UAE lost its entire original share and directed most to Saudi Arabia (94.51 %). Similarly, Libya lost its total share to Saudi Arabia, which suggests that Saudi Arabia is becoming a major destination of bajra imports in the present day. Oman only maintained a small share of 2.82 % to Oman; the rest shifted primarily to Tunisia (36.54 %), Yemen (24.97 %) and Qatar (21.37 %). The rest is directed to smaller portions to UK (10.15 %) and Morocco (4.15 %). This indicates that Oman has reconciled its import diversity and has moved to several export destinations. Tunisia divided all its share principally between Libya (48.32 %) and Oman (51.67 %) creating a near erosion and exhibiting Tunisia's erratic role in the bajra trade. Yemen fully lost its own share to profoundly disperse it with Qatar (17.06 %), UK (40.35 %) and Morocco (42.59 %). For Qatar, UK and Morocco, there are indications of new members on the bajra couch, as they are the recipients of shares from multiple other countries despite not having retained their own shares.

From the analysis indicates that Saudi Arabia is presently the most stable and dominant source of import of bajra from

Table 3. Transition probability matrix for the export of ragi

Country	Nepal	UAE	Malaysia	USA	Qatar	Maldives	Canada	Kuwait	UK
Nepal	0.959554	0.025116	0.003213	0.002862	0.002571	0.002101	0.001612	0.001504	0.001468
UAE	0.134661	0.564871	0.126012	0.068029	0.028626	0.021832	0.021724	0.018618	0.015627
Malaysia	1	0	0	0	0	0	0	0	0
USA	1	0	0	0	0	0	0	0	0
Qatar	1	0	0	0	0	0	0	0	0
Maldives	1	0	0	0	0	0	0	0	0
Canada	1	0	0	0	0	0	0	0	0
Kuwait	1	0	0	0	0	0	0	0	0
UK	1	0	0	0	0	0	0	0	0

Table 4. Transition probability matrix for the export of bajra

Country	UAE	Saudi Arabia	Libya	Oman	Tunisia	Yemen	Qatar	UK	Morocco
UAE	0	0.945112	0.054888	0	0	0	0	0	0
Saudi Arabia	0.579131	0.420869	0	0	0	0	0	0	0
Libya	0	1	0	0	0	0	0	0	0
Oman	0	0	0	0.028204	0.365403	0.249687	0.213655	0.1015	0.041552
Tunisia	0	0	0.483213	0.516787	0	0	0	0	0
Yemen	0	0	0	0	0	0	0.170586	0.403455	0.425959
Qatar	1	0	0	0	0	0	0	0	0
UK	1	0	0	0	0	0	0	0	0
Morocco	1	0	0	0	0	0	0	0	0

India, followed by Libya and Tunisia as possible sources. Because of this, it is important to consider newer markets such as Morocco, UK and Qatar, which are emerging as areas of growing importance. This indicates that new sources of market access and diversification are opportunities coming in the next few years.

Conclusion

The thorough examination of ragi, bajra and jowar export patterns and trade movement from India provides relevant insights on their relative global marketplace behaviour and the stability of trade relations. The Markov chain analysis describes directionality and stability of trade for these products, while the CAGR and CV analysis highlight trends and volatility in export performance. Bajra is the most viable and stable cereal grain export market. The trade links with an average of increased exports, notably in Saudi Arabia and the UK, are particularly strong particularly with an increase in demand in the Middle East. Ragi shows a high level of export volatility, but has stable trade partners, including Nepal and the UAE. Although volume of ragi is declining, the value is increasing, which signifies ragi is shifting to premium or value-added developments, with demand emerging in USA and Malaysia. The change in jowar is the volume of exports is small and not stable, jowar has increasing value, which suggests some demand for niche or new markets. Trade movement is the dynamic element of export markets, Libya, UAE and Saudi Arabia are key contractual developments to note.

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Authors' contributions

SNR carried out the survey, analysed the data and prepared the manuscript. HS assisted in data collection and analysis as part of the research study. DN contributed by developing ideas, reviewing the manuscript and assisting with procuring research grants. AV helped in summarizing and revising the manuscript, while PRS contributed to summarizing and provided additional support for the research study. KS assisted in carrying out the analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

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