Modified Cassava Starch in India: Challenges and Way Forward

A.N. Jyothi, J. Sreekumar and G. Byju

1. Introduction

Starch is a renewable biopolymer made up of glucose units and serves as a reserve carbohydrate in plants. It is predominantly derived from cereals, roots, and tubers. Starch is a versatile industrial raw material due to its renewable nature, biodegradability, biocompatibility, availability, and diverse functional properties. Starch finds extensive applications in food and beverages, pharmaceuticals, textiles, paper, adhesives, bioenergy, and animal feed sectors. The starch market is experiencing a significant growth in recent years on account of the rising demand across these sectors. The food industry remains the largest consumer of starch, utilizing it for various functions such as thickening, stabilizing, and enhancing texture in food products. Growing consumer preferences for natural and organic products, along with the increasing demand for convenient and processed foods have boosted starch use in this area.

Globally, corn (maize) is the primary source of starch, contributing to over 75% of production (Figure 1). This dominance is due to its widespread availability, high starch yield, and affordability. Other key sources include cassava, potato, wheat and rice. The United States of America, China, and the European Union are the major producers of corn starch (1). Demand of cassava starch has been growing due to its gluten-free and versatile nature, with Thailand and Indonesia as major producers. Wheat starch is predominantly utilized in the food industry, particularly in Europe, while potato starch is used in both food and industrial applications. In India, corn is the main raw material for starch and its derivatives, with potato and cassava playing smaller roles.

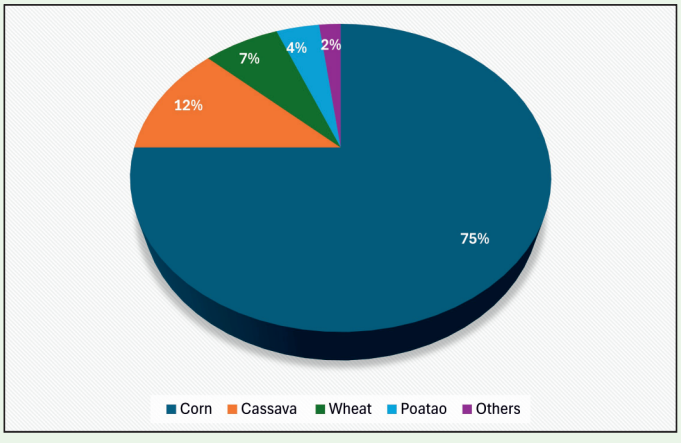

Figure 1. Different sources of industrial starch

The use of native starch in industrial applications is restricted due to its inherent limitations such as poor resistance to high temperatures, pH variations, and shear conditions. To overcome these drawbacks and to improve its functionality and enhance performance across various applications, native starch is usually modified through physical, chemical, or enzymatic methods (2). Modified starches and their derivatives account for more than half of the starch market and serve as thickeners, emulsifiers, gelling agents, and film-forming agents in the food industry (3). Various types of modified starches include starch esters, ethers, cationic starch, oxidized starch, carboxymethyl starch, crosslinked starch, and pre-gelatinized starch. Starch esters and ethers hold the largest market share.

2. Status of Global Starch Market

The global starch market has been steadily growing in recent years, due to the expanding applications of starch in food products, cleaning agents, cosmetic powders and adhesives. The starch market size was valued at ₹ 4,97,000 crores in 2023, and the total starch market revenue is expected to grow at a Compound Annual Growth Rate (CAGR) of 5.7% from 2024 to 2030, reaching nearly ₹ 7,33,000 crores by 2030 (Figure 2), according to a report by maximizemarketresearch.com (MMR) (4). In 2022, the market was 134.5 million tonnes and is projected to grow at a CAGR of 5.1%, reaching 200 million tonnes by 2030 (5) (Figure 2). This growth is largely attributed to the rising demand for convenient, on-the-go food products incorporating starch in their formulations, as well as increasing use in the bakery and confectionery sectors (6).

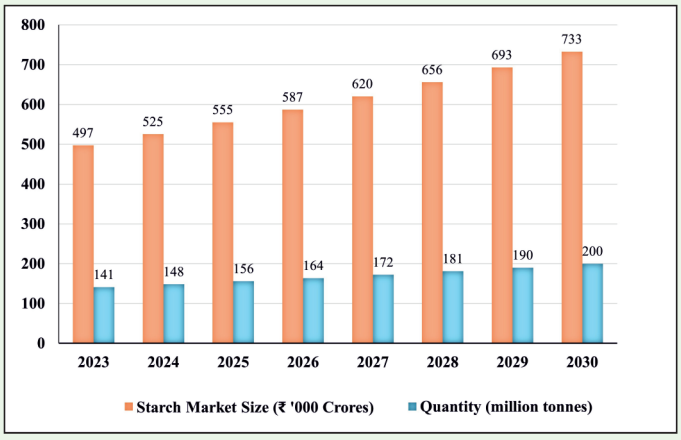

Figure 2. Global Starch Market Forecast 2023-2030 (Source: maximizemarketresearch.com)

2.1. Starch Market Segmentation

2.1.1. Based on Application

The food and beverage industry remains the largest consumer, contributing about 55% of the starch market's revenue. Other significant segments include animal feed, pharmaceuticals, and the retail and food service industries. In the retail and food service sectors, the consumption of native and modified starches is expected to grow by 16% and 10%, respectively, during the period 2022-2027(6). In 2022, China dominated the global native starch market for these sectors with 23.8% share, followed by the United States of America (12.5%) and India (7.8%). In India, the native starch market was 6.4 million tonnes in 2023 and is projected to reach 11.1 million tonnes by 2032. This growth reflects a CAGR of 6.2% during the period 2024-2032, according to a study by IMARC Group (7). Another report from Research and Markets, published in April 2024, forecasts a slightly higher CAGR of 6.31% for the Indian native starch market during 2023-2032 (8).

2.1.2. Based on Starch Type

Corn serves as the leading source for starch and starch derivatives market with a production of approximately 88.3 million tonnes in 2023 (9). The widespread availability of corn as a raw material, coupled with its high starch content, makes it a preferred choice for starch production. Additionally, the relatively low cost of corn compared to other sources makes it an economically viable option for starch production, enhancing its profitability in the market. Wheat, potato and cassava are other starches, but their contribution to starch production is significantly smaller. Cassava is emerging as an increasingly important raw material in the industry.

2.1.3. Based on Region

North America, Asia Pacific region, Europe, Middle East and Africa and Latin America are the major regions of starch market (4). In production and consumption, North America dominates the global starch market. The region's dominance is driven by factors such as the presence of major manufacturers, advanced infrastructure, efficient logistics network and a well-established value chain. The major companies operating in North America are:

- Cargill
- Ingredion Incorporated
- Archer Daniels Midland Company (ADM)

Asia Pacific is the second largest starch market. The key players in this region are:

- Thai Flour Industry Limited , Thailand
- Gulshan Polyols Ltd., India
- Vimal PPCE, India
- China Essence Group Ltd.
- Universal Starch-chem Allied Ltd.

Europe starch market has well-established infrastructure and is characterized by stable growth rates, established market players, and a high degree of market penetration. The major companies in the starch market in this region are:

- Tate & Lyle PLC, U.K.
- Roquette Frères S.A, France
- AGRANA Beteiligungs-AG, Austria
- Beneo GmbH, Germany

3. Global Cassava Starch Market

Cassava (*Manihot esculenta* Crantz) or tapioca, known for its starchy roots, is a tropical root crop cultivated primarily for its high starch content. About half of the total root yield is being used for starch production (10). Cassava is an important industrial crop in many tropical and subtropical countries in South America, Africa and Asia. Globally, cassava is grown in an area of 32.22 million ha producing about 333.68 million tons of tubers with an average productivity of 10.36 tonnes ha^{-1} (FAO STAT, 2023) (11). The major share of area (80.5%) and production (63.9%) is in Africa, followed by Asia (13% and 27.8%, respectively).

Although corn has been the leading crop for starch production, production of cassava starch is growing at an annual rate of 3%, contributing approximately 7% to global starch output (OECD/FAO, 2021) (12). Cassava stands out among different starch sources due to its superior starch accumulation, year-round availability, cost efficiency, and resilience to adverse conditions such as drought, poor soils, pests, and diseases. Its ease of starch extraction further enhances its appeal (13). The rising demand for cassava starch is driven by its unique characteristics, including the gluten-free nature, neutral taste and flavour, high paste viscosity, and clarity. These qualities make it highly desirable for diverse applications in both food and non-food industries, ranging from gluten-free products to industrial adhesives and biodegradable materials.

The global cassava starch market has experienced significant growth in recent years, with the starch production reaching 8.8 million tonnes in 2020 (10,14). Asia-Pacific region dominating the market, accounting for approximately three-fourth of global output. Thailand leads global cassava starch production (2-3 million tonnes per year), followed by Vietnam and Cambodia (14). Several factors are driving the expansion of the cassava starch market. The rapid growth of the global food industry, fuelled by urbanization, a growing working population, and rising household incomes in emerging economies like India and China have increased the demand for ready-to-eat food products, stimulating the cassava starch industry (14). While cassava starch was historically used primarily in food applications, its versatility and availability have led to its adoption in non-food industries such as pharmaceuticals, adhesives, paper, textiles, and bioethanol production. The expansion of these sectors further propels market growth. Additionally, rising health consciousness and increasing cases of diabetes have boosted demand for artificial sweeteners, which is expected to support the continued growth of the cassava starch market in the years ahead (14).

4. Status of Cassava Starch Production and Market in India

Cassava was introduced in India during the later part of 18th century. In India, cassava is cultivated in an area of 1,66,000 ha with a total production of 5.94 million tonnes and a productivity of 35.77 t ha^{-1}(11). Cassava is predominantly cultivated in the southern states of India, viz., Kerala, Tamil Nadu, and Andhra Pradesh. Kerala and Tamil Nadu account for about 80 per cent of the total cultivated area. While cassava serves as a secondary staple food in Kerala, it is primarily an industrial crop in Tamil Nadu. The cassava starch industry in India is well-established, primarily focusing on the production of native starch and sago. The SPAC Starch and Derivatives, and Varalakshmi Starch Industries Pvt. Ltd. are the two major producers of cassava starch and sago, holding approximately 40-50% of the total market share. Salem Starch and Sago Manufacturers' Service Industrial Co-operative Society Ltd. (SAGOSERVE), functioning under the administrative control of the Director of Industries and Commerce, Government of Tamil Nadu facilitates the credit and marketing of cassava. In 2021-2022, SAGOSERVE has marketed about 1,25,800 tonnes of sago (Sabudana), a processed food product made from cassava starch and 35,000 tonnes of starch. However, the market share of SAGOSERVE is about 25-30% of the total starch and sago production in Tamil Nadu.

4.1. Cassava Starch Export, Import and Trade Balance in India

The country wise export of cassava starch from India in 2023 is presented in Figures 3. India's total cassava starch export was 3,305 tonnes according to World Integrated Trade Solution (WITS) data of World Bank, which corresponds to a trade value of ₹ 2,535 lakhs, and United States of America was the highest importer from India (1,455 tonnes, ₹ 1,453 lakhs) (15). Other major importers of cassava starch from India were Kuwait (954 tonnes, ₹ 527 lakhs), Nepal (625 tonnes, ₹ 360 lakhs), United Arab

Emirates (82 tonnes, ₹ 52 lakhs) and Sri Lanka (62 tonnes, ₹ 47 lakhs). The total cassava starch import to India in 2023 was 1,694 tonnes which worths ₹ 843 lakhs, with the major share from Cambodia, Vietnam and Thailand (Figure 4). The quantity and trade value for major countries were as follows: Cambodia (1,648 tonnes, ₹ 809 lakhs), Vietnam (39 tonnes, ₹ 20 lakhs), Brazil (2 tonnes, ₹ 5.65 lakhs), Thailand (6 tonnes, ₹ 5 lakhs).

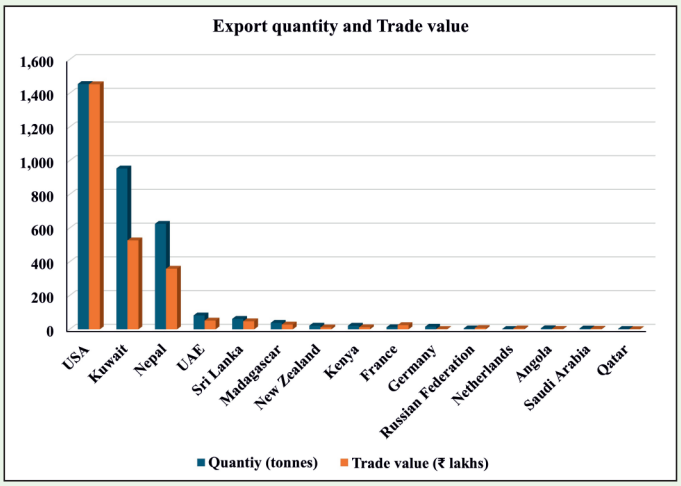

Figure 3. Country wise export of cassava starch from India in 2023

[Source: World Integrated Trade Solution (WITS) data of World Bank, 2024]

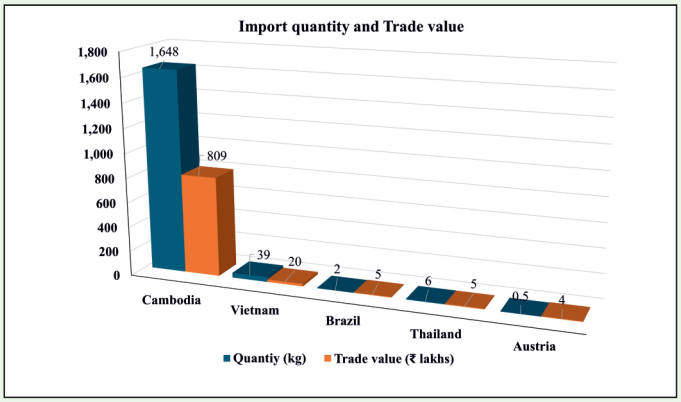

Figure 4. Country wise import of cassava starch in India in 2023

[Source: World Integrated Trade Solution (WITS) data of World Bank, 2024]

Cassava starch market has shown robust demand and promising growth trends. The net export of cassava starch from India during the period 2018-2023 showed a significant growth with a change from negative trade balance to positive figures from 2021 onwards indicating an increased export demand for cassava starch from India (Figure 5). According to the latest cassava market research report by IndustryARC, the Indian cassava starch market is projected to reach ₹ 3,115 crores by 2030, with an expected CAGR of 7.9% from 2024 to 2030 (16). The East and Northeast India is anticipated to experience the highest growth of CAGR 9.0% in the cassava starch market between 2024 and 2030. Along with the rising demand for cassava starch in various industries, strategic government initiatives aimed at promoting agricultural processing industries in these regions fuel this growth. The favourable geographical conditions in the East and Northeast regions, conducive for cassava cultivation, support this growth, making these areas pivotal in shaping the future landscape of the cassava starch market in India.

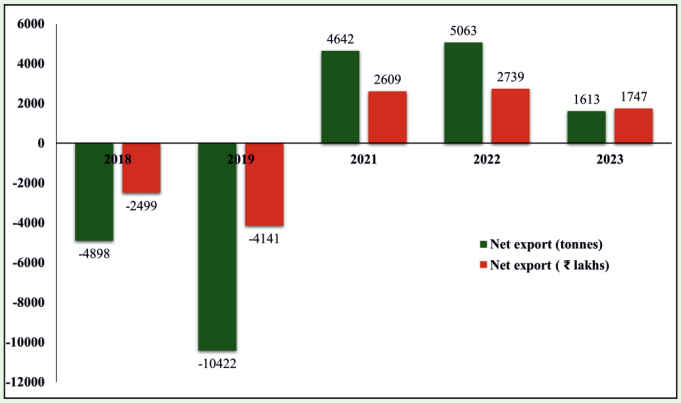

Figure 5. India cassava starch trade balance (2018-2023)

[Source data: World Integrated Trade Solution (WITS), World Bank, 2024]

4.2. Cassava Starch Market Segmentation in India

4.2.1. Based on Application

About 60% of the total cassava production in India is used for the industrial production of starch and sago, a processed food product from cassava, with Tamil Nadu being the major production hub. On an average, 200 kg of sago can be produced from one tonne of cassava tubers. Sago is mostly marketed in states such as Uttar Pradesh, Madhya Pradesh and Gujarat (17). Cassava starch is also used in food, textile, adhesive, paper and modified starch industries. It is used as a thickener, stabilizer, and texture enhancer in food products, including soups, sauces, bakery goods, and snacks.

4.2.2. Based on Region

In India, cassava starch and sago production occurs almost completely in the state of Tamil Nadu. Three hundred and eighty five starch/sago manufacturing industries are registered as members of SAGOSERVE. These factories are in Salem and Namakkal districts of Tamil Nadu.

5. Global Status of Modified Starch Sector

5.1. Global Modified Starch Market Overview

The modification of starch alters its cooking properties, reduces retrogradation, and enhances film formation and adhesion. It also improves the gelling potential of starch pastes. Modified starch is widely used in fast foods to enhance the flavour, texture, and overall taste of food, driving demand during the forecast period. According to a report published by DataM Intelligence for Global Information Inc., modified starch market reached ₹ 1,07,563 crores in 2022 and is expected to reach ₹ 1,41,807 crores by 2031 growing at a CGAR of 3.5% during the forecasting period of 2024-2031 (18). The global market for modified starch was valued at ₹ 1,30,702 crores in 2024 and is projected to grow to ₹ 1,95,626 crores by 2033, with a CAGR of 4.61% anticipated between 2025 and 2033 (18). The global modified starch market forecast 2031 report published by ResearchAndMarkets.com, which analyzes the modified starch market across five major geographies, says that global modified starch market will reach ₹1,53,596 crores by 2031 at a CAGR of 4.1% from 2024 to 2031 with a volume of 28.65 million tonnes (18). This growth is mostly driven by the growing demand for convenience and processed foods, widening food applications of modified starch, increasing investments in the starch market, the growing demand for bio-based products, technological advancements in starch modification techniques, and the rapid growth of the bakery industry.

5.2. Modified Starch Market Segmentation

5.2.1. Based on Region

According to a report recently published by IMARC Group, North America currently dominates the modified starch market with a market share of about 42.7% in 2024 (19). The Asia-Pacific region is projected to hold the largest market share and maintain a dominant position in the starch derivatives market during the forecast period of 2024-2034, according to Precedence Research (20). Key countries in this region include China, India, Japan, South Korea, and others. The growing demand for functional foods, the preference for clean-label products, and the need to reduce production costs are significant factors driving the adoption of starch derivatives, especially in China, India, and Bangladesh.

5.2.2. Based on Starch Type

Based on starch type, the modified starch market segment includes corn, wheat, cassava, potato, and other minor starches others (21). According to the report of ResearchAndMarkets.com, and IMARC group corn starch accounts for the largest share of the modified starch market in 2024 (19, 22). The growing use of corn as a key ingredient in producing modified starch is attributed to its numerous advantages, including versatility, affordability, wide availability, and extensive applications in the food and beverage sector. Corn starch is particularly sought after for its textural properties, making it an ideal thickening agent in industries such as dairy and beverages. Additionally, corn starch holds a significant advantage in the production of gluten-free products, addressing challenges associated with wheat-derived starches. The increasing demand for clean-label ingredients and products is also reshaping the global food and beverage industry (23).

5.2.3. Based on Application

The Food & Beverages segment dominated the modified starch market in 2022 and is projected to be the faster-growing segment during the forecast period of 2022-2030 according to marketresearchfuture.com (21). The shift in consumer preferences towards low-calorie foods has prompted an increase in food and beverage companies utilizing modified starch. This trend is essential to meet the rising demand for functional

and low-calorie food products, contributing to the growth of the starch derivatives market. Consequently, ingredient manufacturers have developed solutions that enable food producers to cater to this evolving demand. Among the different modified starches, the enzymatically modified starch segment is projected to register the highest CAGR of 4.4% during the forecast period of 2024-2031. Enzymatic modification enhances the resistant starch content of starch, thereby expanding its application in sectors like food and beverage, animal nutrition, and pharmaceuticals. Enzymatic modification also offers an efficient and cost-effective means of converting starch solid wastes, further contributing to its increased adoption.

6. Status of Modified Starch Sector in India

Exports play a significant role in driving the growth of the starch and starch derivatives market in India, as the country experiences high production levels but relatively low domestic consumption. This export demand helps offset the imbalance, contributing substantially to market expansion. The Indian starch and starch derivatives market is competitive, with many domestic and multinational players competing for market share (25). The key players in India's starch market include ADM, Tirupati Starch & Chemicals Ltd., Gayatri Bio Organics limited, Universal Starch Chem Allied Ltd., Sahyadri Starch & Industries Pvt. Limited, among others.

India's primary export destinations for modified starches in 2021 included Saudi Arabia (₹109 crores), the United Arab Emirates (₹ 63 crores), Bangladesh (₹ 17 crores), Kuwait (₹ 16 crores), and Qatar (₹ 15.3 crores) (25). On the other hand, India's imports of dextrins and other modified starches in 2021 amounted to ₹ 653 crores, making it the 15th largest global importer of these products. Thailand was the primary source of India's imports in this category, accounting for ₹ 268 crores, followed by China (₹ 180 crores), the United States (₹ 74.8 crores), the Netherlands (₹ 42.7 crores), and France (₹ 32.2 crores). A growth in imports between 2020 and 2021 was observed from Thailand, amounting to ₹ 77.3 crores, followed by China with an increase of ₹ 13.1 crores and Belgium with ₹ 8.2 crores.

Among the various segments in India's starch and starch derivatives market, modified starches have experienced the fastest growth (26). This is largely attributed to the increasing demand for low-calorie food products, fuelled by the rising prevalence of obesity and diabetes and growing health awareness. Modified starch is a versatile ingredient utilized across multiple industries, including food, papermaking, cosmetics, personal care, and textiles (2, 24). Among different starch and starch products, demand is the highest (34.1%) for glucose and glucose syrup, followed by maize starch (26.2%), and dextrins and other modified starches (25.8%) (27). The modified starch market is a significant and growing sector in the country. During 2021, India exported dextrins and other modified starches with a total export value of ₹ 317.6 crores. This positioned India as the 15th largest exporter of these products worldwide (28).

7. Global Status of Modified Cassava Starch

Modified cassava starch serves as a highly adaptable ingredient across various industries, including food, pharmaceuticals, and manufacturing, due to its gluten-free and non-GMO properties. It is widely used in food and beverages, paper production, textiles, adhesives, pharmaceuticals, cosmetics, and personal care products. The use of modified cassava starch enhances product quality, functionality, and shelf life while offering cost-efficient solutions for manufacturers. In food applications, it provides benefits such as improved moisture retention, freeze-thaw stability, and enhanced texture. Notably, sweeteners derived from cassava starch are projected to dominate the global market (29).

A recent study published in January 2025 by Verified Market Reports says that cassava modified starch market size was ₹ 30,411 crores in 2023 and is expected to reach ₹ 49,376 crores by 2033 with a CAGR of 5.5% during the forecast period of 2026-2033 (30). Reliable Business Insights estimates a CAGR of 11.8% from 2024 to 2031 (31). Key growth drivers include rising demand for processed foods, advancements in the pharmaceutical sector, and increased awareness of diverse applications of

starch. A recent research report states that the global modified cassava starch market is expected to grow significantly between 2025 and 2033 (32).

According to Volza's import data, the top three importers of modified cassava starch are United State of America, Indonesia, and India (32). United States leads the world in modified cassava starch imports with 13,050 shipments, followed by Indonesia with 6,509 shipments, and India taking the third position with 3,899 shipments during November 2023 to October 2024.

Leading companies in the modified cassava starch market are:

- Tate & Lyle
- Ingredion
- Cargill
- AGRANA Starch
- Psaltry International
- Visco Starch
- Vaighai Agro
- KPN Pharma
- SPAC Starch Products
- Ekta International
- Sanstar Bio-Polymers
- Aryan International
- Ng Wah International Development
- Thai Foods Product International
- Asia Fructose

These companies are focusing on strategic partnerships and new product development to enhance their global market presence. In early 2021, Cargill Inc. expanded its specialty tapioca starch range in the Asia-Pacific market through a collaboration with Starpro, a leading producer of food-grade cassava starch in Thailand. This partnership is aimed at addressing the evolving needs of food manufacturers and aligning with regional consumer preferences. Likewise, in January 2021, Tate & Lyle introduced new tapioca-based starch products, including REZISTA MAX thickening starches and BRIOGEL gelling starches (23). The market outlook remains positive as global demand for cassava starch continues to rise across various industries.

8. Status of Modified Cassava Starch in India

According to Volza's report on export trade (32), over 48 countries contribute to the global export of modified cassava starch. The top 10 modified cassava starch exporting countries during the period 2014 to January 2019 are shown in Figure 6. Thailand is the largest exporter of modified cassava starch with 18,897 export shipments by 378 suppliers accounting for a market share of 40%. Following Thailand, Vietnam emerges as a key player with 4,074 shipments, contributing to a 13% market share. China also makes a mark with its 816 shipments, corresponding to a 10% market share. Modified cassava starch is exported globally to over 60 countries from India. According to Volza's database, there are over 1,463 active global modified tapioca starch buyers, with 37 buyers importing from India. During the period 2020-2024, India exported 2,227.5 tonnes of modified cassava starch to seven countries *viz*., Sri Lanka, Brazil, United States of America, Vietnam, Iran, Russia and Saudi Arabia. During this period, the largest importer of modified cassava starch from India was Sri Lanka, with an export quantity of 2,162 tonnes, followed by Brazil with 121 tonnes.

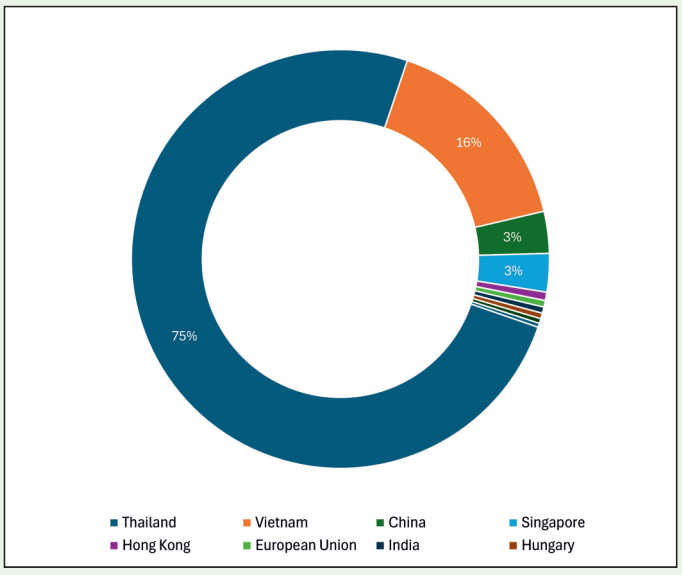

Figure 6. Top 10 modified cassava starch exporting countries (2014- till January 2019)
(Source: Volza's report on export trade)

Figure 7 depicts the export trends of modified cassava starch from India in terms of quantity and export value during the period 2014-2024. The data highlights a notable surge in exports during 2023 and 2024, reflecting a strong market recovery following the COVID-19 pandemic.

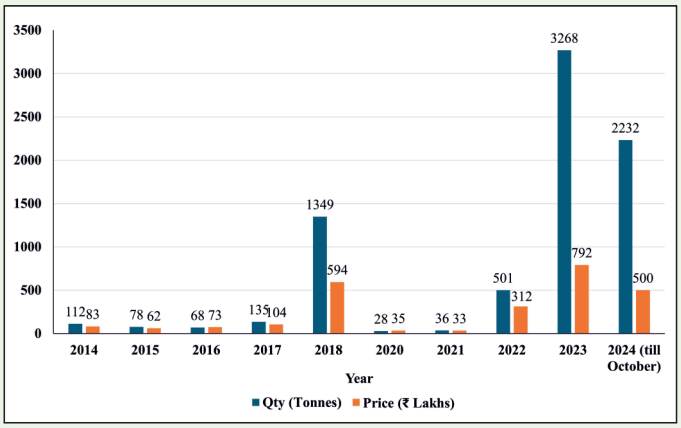

Figure 7. Export details of modified cassava starch from India during 2014-2024

According to Volza's Export data which was derived from Volza's Suppliers & Exporters Directory of modified cassava starch based on global export import records across over more than 80 countries, India exported 22 shipments of modified tapioca starch from October 2023 to September 2024 which involved 5 exporters and 8 buyers, with a growth rate of -19% compared to the preceding twelve months (33). There are a total of 20 modified cassava starch exporters in India, who exports modified cassava starch to about 40 buyers globally. In the period from November 2023 to October 2024, 8 suppliers were active, with Navapro Internationals, SPAC Starch Products India Ltd. and Eiamsiri Starch Co. Ltd. accounting for 91% of India's total modified cassava starch exports (Figure 8). Navapro Internationals is the leading modified cassava starch exporter in India, accounting for 65% of the total market with 15 shipments. SPAC Starch Products India Ltd. follows in second place, contributing 17% of the total with 4 shipments. Other leading exporters are Varalakshmi Starch Industries Pvt. Ltd., Spectrum Polymers Pvt. Ltd., Angel Starch Foods Pvt. Ltd., and Nithya Paching Pvt. Ltd (34).

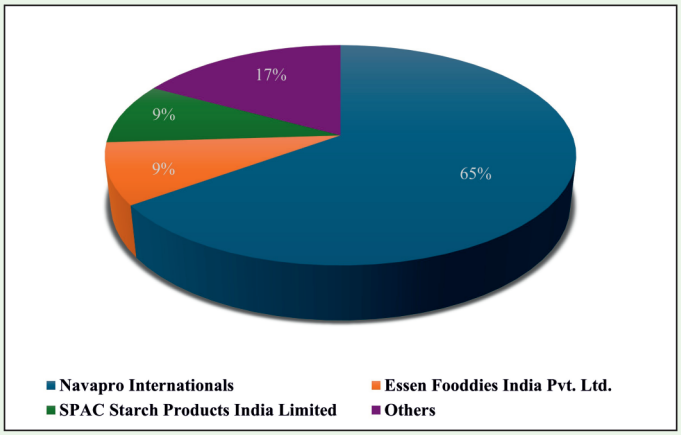

Figure 8. Major cassava starch exporters in India during the period March 2023 - February 2024 (Source: Volza.com)

According to Volza's Modified Tapioca Starch Import data of India, Thailand and Vietnam remain the primary sources for India's imports (35). India imported 810 shipments of modified cassava starch during October 2023 to September 2024. The country witnessed significant growth in its imports of modified cassava starch, with 38 foreign exporters supplying to 62 Indian buyers. This reflects a 57% increase over the previous 12 months. Notably, in September 2024 alone, India recorded 74 shipments, representing a 40% year-on-year growth compared to September 2023.

The major importers of modified cassava starch are:

- Ingredion India Pvt. Ltd.
- Rhea Chemicals
- Connell Bros Company India Pvt. Ltd.
- ITC Limited
- Gadre Marine Export Pvt Ltd.
- N R Agarwal Industries Limited
- JK Paper Ltd.
- Excipients House

Ingredion India Pvt. Ltd., Rhea Chemicals and Connell Bros Company India Pvt. Ltd. accounted for about 69% of India's total modified cassava starch imports during November 2023 to October 2024 (Figure 9). Ingredion India Pvt. Ltd. is the leading modified cassava starch importer in India, constituting 46% of the total with 158 shipments, followed by Rhea Chemicals, with a 12% share of

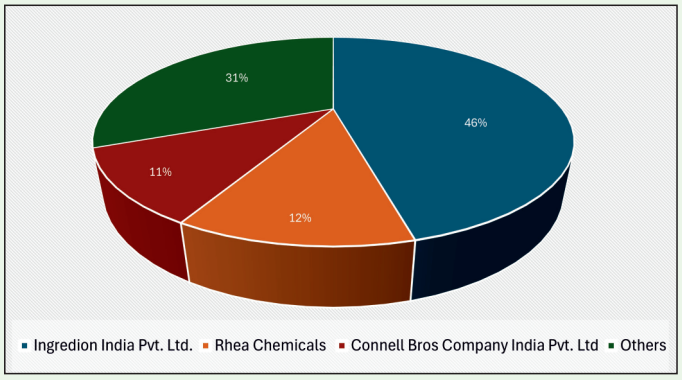

Figure 9. Major modified cassava starch importers in India (Source: Volza.com)

the total, equivalent to 66 shipments and Connell Bros Company India Pvt. Ltd. making up 11% of the total with 39 shipments during this period.

9. Modified Cassava Starch: Research at ICAR-CTCRI

ICAR-CTCRI is in the process of developing modified starches of casava as a part of its effort to diversify the use of cassava starch beyond sago production. Processes have been developed by ICAR-CTCRI to produce various physically modified and chemically modified starches. The physically modified starches are heat-moisture treated starch, annealed starch, steam-pressure treated starch, porous starch and pregelatinized starch, whereas the chemically modified ones include starch esters, starch ethers, crosslinked starch, oxidized starch, acid modified starch, phosphorylated starches and starch-graft-copolymers with specific end uses. The major starch esters are cassava starch succinate, starch octenyl succinate, starch citrate, and starch monophosphate. The crosslinked starches include epichlorohydrin-crosslinked starch, distarch phosphate, and succinylated distarch phosphate, while hydroxypropylated starch is a starch ether prepared with propylene hydroxide.

The different types of modified starches developed by the Institute and their uses are described below.

9.1. Physically modified starches

9.1.1. Heat-moisture treated cassava starch

This is a hydrothermal treatment which reduced the paste viscosity, swelling volume and paste clarity while enhancing the solubility and paste stability(36). By manipulating the treatment conditions, modified starches with desirable characteristics can be obtained. As physical method has the advantage of not using any chemicals this modification offers a better scope for a safe and convenient technique for modifying starch for specific applications.

9.1.2. Annealed cassava starch

Annealing is another hydrothermal treatment for altering starch properties. Annealed cassava starch has reduced viscosity and *in vitro* starch digestibility, while increased hardness, gumminess, adhesiveness, and decreased springiness for the starch gels (37). Due to the low setback viscosity, annealed starches could be utilized in the canned and frozen food industries. The decrease in granular swelling and amylose leaching, and the increase in heat and shear stability are desirable properties for noodle manufacture.

9.2. Chemically modified starches

9.2.1. Saponified cassava starch-graft-copolymer as superabsorbent polymer

A semi-synthetic superabsorbent polymer based on cassava starch and a bench scale process for its production have been developed (38). The superabsorbent polymer has cassava starch backbone (about 30-35%) and is semi-synthetic in nature with an absorption capacity of 300-400 g/g of the dry sample. The absorbed water is retained by the polymer and slowly released into the soil. It also improves soil physical properties such as porosity, water holding capacity, and electrical conductivity, soil nutrient and organic carbon status as well as soil microflora. Under controlled conditions such as in greenhouses for plant nurseries, ornamental and medicinal plants and high-tech agriculture, it can be more effectively used. The technology is included in the technology list of AGRINNOVATE India Ltd. and was also commercialized to M/s SKR Biotech, 5, Mohata Market, Main Road, Wardha, Maharashtra in 2020.

9.2.2. Cassava starch esters as Resistant Starch (RS4 type)

Resistant starch (RS) is the fraction of starch, which is not digested in the small intestine, while reaching large intestine undergoes fermentation and enhances butyrate production, which is essential for colon health. It mimics the physiological functions of dietary fibre and acts as pre-biotics. A process has been developed for producing octenyl cassava starch succinate with lower *in vitro* digestibility than native starch which can act as a resistant starch (39). In the cooked samples the slowly digestible starch (SDS) and RS contents were significantly higher (38.4±0.88% and 20.8±0.62% respectively), compared to native cassava starch (20.5±0.41% SDS and 1.5±0.39% RS). Another RS4 type cassava starch was synthesized by esterification with citric acid and the modified starch has an RS content of 39.6±0.54% and SDS content of 22.4±0.58% (40). The estimated glyceamic index of the octenyl succinylated starch and starch citrate were 60.3±0.44 and 59.4±0.52, respectively, while that of native starch was 91.3±2.68. Cassava starch octenyl succinate is also an effective emulsifier for food products. Cassava starch citrate can be used as a thickener in different food products. This technology 'Cassava and Sweet potato Resistant Starch - RS4 type (Chemically modified)' has been certified by ICAR in 2024. Cassava and Sweet potato Resistant Starch - RS4 type (Chemically modified) and Cassava Resistant starch (RS5 type) are included in the technology list of AGRINNOVATE India Ltd. for commercialization.

9.2.3. Cassava starch succinate

Process was developed to produce cassava starch succinate by reaction with succinic anhydride. Apart from the slurry reaction (41), a microwave aided dry phase reaction technique was developed for the very fast and solvent-free synthesis of cassava starch succinates (42). This modified starch has higher water binding capacity and paste viscosity. Cassava starch succinate is a food thickener and a binding agent for tablets in pharmaceutical industry.

9.2.4. Octenyl succinate cassava starch as excipient for pharmaceuticals

Microwave-assisted synthetic process was developed for producing octenyl succinate cassava starch as an excipient for controlled release of therapeutic drugs such as theophylline (43).

9.2.5. Cassava starch monophosphate

Cassava starch monophosphate is a low temperature gelling starch and can be used in food products as gelling agent and thickener.

9.2.6. Crosslinked cassava starch

Cassava starch crosslinked with epichlorohydrin has very stable starch pastes or non-gelatinizable nature and hence useful as dusting agents for surgical gloves and other high temperature applications (44). Cassava distarch phosphate, synthesized with sodium tripolyphosphate and sodium trimetaphosphate can act as a thickening agent for food products (45).

9.2.7. Hydroxypropyl cassava starch

Hydroxypropyl cassava starch has good freeze-thaw stability and high paste viscosity (46). It is a thickening agent especially for refrigerated products.

9.2.8. Oxidized cassava starch

Oxidized cassava starch has low hot paste viscosity, clear pastes, improved film forming properties and lower tendency to retrograde. This can be used in textile, paper and adhesive industries.

9.2.9. Acid modified cassava starch

This is a partially degraded, thin boiling starch with lower paste viscosity and increased solubility, suitable for use in formulation of adhesives.

9.2.10. Succinylated cassava distarch phosphate

Succinylated cassava distarch phosphate is a dual modified starch. It can be used as an emulsifier and fat substitute in foods.

9.2.11. Porous cassava starch

Porous cassava starch has high water binding capacity and is useful as an adsorbent for pollutants

in water and also as a carrier for active substances for extended delivery.

9.2.12. Cassava starch phosphate carbamate

cassava starch phosphate carbamate possesses high water absorption and dye adsorption capacities. This modified starch can be used for removing synthetic dyes such as methylene blue from aqueous effluents.

9.2.13. Cassava starch-graft poly (methacrylamide)

Grafted starches are modified starches, where synthetic or natural polymer chains are chemically grafted onto the starch backbone to enhance the functional properties of starch and making it suitable for a wide range of industrial applications. Free radical initiated polymerization technique was standardized for synthesising cassava starch-graft-poly(methacrylamide) polymers, which are useful as flocculating agent for water clarification and sizing agent for textile industry (47).

10. Prospects of Modified Cassava Starch in India

The growth of the modified cassava starch industry is primarily driven by the rising demand for clean-label and gluten-free food products, alongside the increasing popularity of processed and convenience foods. Modified cassava starch demand has been growing due to its improved functional attributes such as better stability, thickening, and gelling properties. The versatility and adaptability of cassava starch in various applications make it a preferred ingredient in the food industry, particularly in bakery and dairy products, as well as sauces and dressings. Its use is particularly notable in the food and beverage industry, where it serves as an effective thickening agent, stabilizer, and a texture enhancer.

The modified cassava starch market has great opportunities in emerging economies where the demand for processed food products is on the rise. The increasing urbanization and changing lifestyles in countries like India and China present lucrative avenues for market expansion. Urban populations in developing nations are expected to double by 2050, leading to higher demand for convenient and ready-to-eat food products. Additionally, the growing trend of health and wellness is driving innovation in the food industry, prompting manufacturers to explore new products such as gluten-free and vegan foods, where modified cassava starch can serve as a vital ingredient.

Increased awareness of environmental sustainability and stricter regulations have boosted the demand for biodegradable products, making them a rapidly growing segment in India's cassava starch market. Cassava starch plays a vital role in the production of biodegradable alternatives to conventional plastics and packaging materials (16). In the pharmaceutical industry, its exceptional binding and disintegration properties make it a valuable ingredient, while the paper and textile industries benefit from its adhesive and coating capabilities for improved performance and product quality.

Cross-linked cassava starch segment is forecasted to grow with the highest CAGR of 11.3% in the India cassava starch market during the period 2024-2030, which is attributed to the unique properties such as improved stability, resistance to acidic and high-temperature conditions, and enhanced texture, making it ideal for use in food, textile, paper, and adhesive industries (34).

The increasing import trends of modified cassava starch into India reflect its rising demand within the domestic market. Concurrently, there has been a notable growth in India's export of dextrin and other modified cassava starches. This dual increase in both domestic and international demand underscores the immense potential of native and modified cassava starch as a valuable commodity for future market opportunities.

10. Challenges of Modified Cassava Starch in India

Price fluctuations of the tuber and starch caused by seasonal nature of the crop, limited area of cultivation of cassava and the resulting shortage in starch production, less product diversification in the form of modified starches as the major product from cassava starch is sago, are the major challenges faced by modified cassava starch sector in India. The limited production of specialty and modified starches to meet diverse industry demands remains a critical factor restricting the market's growth in India.

The production of cassava starch is significantly influenced by the availability and cost of raw materials. The seasonal nature of cassava, an annual crop with tuber availability concentrated between November and April, poses challenge, as factories face difficulties to operate during off-seasons. Wide fluctuations in the prices of tuber are being observed every year in the country, which affect the overall production costs of starch and consequently that of the modified starches.

In India, 90% of the cassava cultivation is in states of Kerala and Tamil Nadu. In Kerala, cassava is a staple food and is not used for starch production. In Tamil Nadu, which produces about 60-65% of total cassava tubers in the country, the major share of cassava starch is used for sago production. Hence, the availability of this starch for modified starch sector is limited. In India, the main competitor of cassava starch in the modified starch sector is corn starch, which is available at a cheaper rate and more abundant than cassava starch.

Cassava tubers undergo post harvest deterioration after about 48 h of harvest and is faster if cuts/wounds are present in the tubers. Because of the short shelf life, the tubers need to be processed immediately after harvest and this necessitates the availability of factory facilities near the farms.

Currently, a significant gap exists between research outcomes and their implementation in commercial industries due to lack of proper collaborations and sufficient advertisement of the products among the end users. Additionally, regulatory hurdles surrounding food safety and labeling can pose challenges for market entry, particularly for new players.

The availability of modified starches of cassava with diverse functionality is very limited in the market. There is a pressing need for research and development to improve the functionality of modified cassava starch. As consumer preferences evolve, researchers must continuously innovate to meet the changing demands.

The presence of synthetic alternatives in the market may pose a challenge to the growth of modified cassava starch, as some manufacturers opt for cheaper and readily available substitutes. These factors may limit the expansion of the market, especially in price-sensitive regions. The competition among major players in the modified starch market can impact pricing strategies and market share, requiring companies to adopt strategic initiatives to differentiate themselves.

11. Way Forward

The limited raw material availability in the modified cassava starch industry can be addressed through expansion of cultivation of the crop to nontraditional areas. Staggered planting in suitable cultivation areas and encouraging short duration varieties are strategies to ensure the year round supply of the tubers which also helps to address the price fluctuations of tuber as well as starch in the market. To mitigate the challenges on fluctuating raw material prices and consequent disruption of the supply chain, starch producers must also adopt robust risk management practices and build strategic partnerships with suppliers to stabilize input costs.

Apart from sago production, diversification of the use of cassava starch through modification will help to uplift the modified cassava starch sector. Modification of starch through chemical, physical

and enzymatic techniques ensure diverse functionality for different applications. Investments in research and development to enhance the functional properties of starches and integrate sustainable practices can support industry growth. Research initiatives emphasizing high-yield cassava varieties, varieties with enhanced shelf life, environmentally sustainable agricultural practices, and cost-effective modification processes are also crucial. A closer collaboration between research institutions and industry stakeholders is essential in developing scalable and commercially viable modified starches with diverse functionalities. Public-private partnerships can bridge the gap between research innovations and their commercial applications, making cassava starch modification both practical and profitable.

The adoption of advanced processing technologies offers significant growth potential for India's cassava starch market. Modernizing cassava starch processing technology is essential for Indian manufacturers to produce a broader range of modified starches catering to diverse industries. Government subsidies and incentives targeted at small and medium enterprises can facilitate modified cassava starch industry. Strengthening extension services will ensure that farmers gain access to the latest advancements in improved varieties, farming techniques and technology. Awareness campaigns highlighting the advantages of cassava starch over other starches could increase demand.

Once considered primarily an industrial crop, cassava has become increasingly popular Once regarded as a subsistence crop, it has transitioned into a valuable commodity, due to its versatility across sectors such as food, pharmaceuticals, adhesives and textiles. In brief, expansion of cultivation of cassava in the country, controlling price fluctuations by ensuring the year round availability of tubers and enough starch for product diversification through modification, and building awareness about the advantages of cassava starch over other starches are key components to be addressed in the future for making the modified cassava starch sector bright in India.

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G. Byju
Director

भाकृअनुप - केन्द्रीय कन्द फसल अनुसंधान संस्थान
(भारतीय कृषि अनुसंधान परिषद्)
श्रीकार्यम, तिरूवनन्तपुरम 695 017, केरल, भारत
ICAR-Central Tuber Crops Research Institute
(Indian Council of Agricultural Research)
Sreekariyam, Thiruvananthapuram 695 017, Kerala, India
Tel. No. : 91 (471)-2598551 to 2598554; E-mail: director.ctcri@icar.org.in, Website: https://www.ctcri.org