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Tiger Nut (*Cyperus esculentus*) Tuber: A Sustainable Resource for Industrial Starch: A Review

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Abstract: *Tiger nut starch, a unique C-type starch extracted from tiger nuts (Cyperus esculentus), exhibits promising functionalities for various industrial applications. This review explores the sources of starch, highlighting tiger nut starch's characteristics and extraction methods. The paper then discusses starch modification techniques, including chemical, physical, enzymatic, and genetic methods, along with their advantages and limitations for tiger nut starch. Finally, the review explores the potential applications of tiger nut starch in the food, pharmaceutical, and other industries. The review led to the observation that (i) Tiger nut starch as a C-type starch with distinct properties compared to other starches (ii) Various extraction methods for tiger nut starch, including alkaline, water, and enzymatic techniques (iii) Modification methods to enhance the functionality of tiger nut starch for diverse applications (iv) Potential applications of tiger nut starch in food products, pharmaceuticals, and other industries*.

Keywords: *Cyperus esculentus;* Modification; Physiochemical properties; Starch extraction; Tigernut

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1.0 Introduction

Millions of people have been enjoying chewing raw tiger nut (*Cyperus esculentus*) tubers for thousands of years, with less focus being placed on processing the tubers into more useful goods (Maduka and Ire, 2018). According to Abdulkader *et al*. (2017), *C. esculentus* is a perennial crop that is widely grown throughout Asia, East Africa, parts of Europe, especially Spain, and the Arabian Peninsula. In Nigeria, *C. esculentus* is also widely distributed both in rainy and dry seasons, and it is consistently accessible.

With the growing world population, it is important to make the most of easily accessible crops like *C. esculentus* for the production of more beneficial goods. Typically, *C. esculentus* is processed into three valuable products: tiger nut milk, tiger nut flour, and tiger nut oil. It could also be used to create a variety of goods, both edible and inedible (Yu *et al*., 2022; Maduka and Ire, 2018; Achoribo *et al*., 2017).

Many studies (Zhang *et al*., 2022; Lv *et al*., 2022; Djomdi *et al*., 2020; Zhu *et al*., 2020; Maduka *et al*., 2019), reported that, *C. esculentus* has emerged as a novel and important starch resource. It has been discovered that tiger nut starch differs from other starches, such as potato and maize starch, in certain ways. Tiger nut starch has been found to exhibit remarkable gel consistency, significant retrogradation propensity, and great freeze-thaw stability. It also has the potential to be used as a vehicle for the delivery of chemicals that are useful to the food and pharmaceutical industries, such as flavours, colourants, antioxidants, and pharmaceutically active proteins (Abegunde *et al*., 2013). It is no secret therefore that the development of food products to improve certain aspects of the product's quality requires the use of starch (Abegunde *et al*., 2013).

However, tiger nut starch manufacturing and application are still very low, mainly due to inadequate knowledge of its industrial potential. Hence the focus of this review is to add to the existing knowledge about the uniqueness of tiger nut starch and its potential for industrial application.

2.0 Sources of Starch

It is possible to obtain starch from both conventional and unconventional sources. Corn, cassava, potatoes, wheat, rice, and different tubers are examples of conventional (traditional) sources of industrial starch (Caicedo *et al*., 2023). Studies on non-conventional sources of starch have revealed some encouraging findings. Sarkar *et al*. (2021) listed seeds and legumes such as durian, jackfruit, loquat, lychee, mango, tamarind, and pine as non-conventional sources of starch. Some non-conventional sources that have been found in some parts of Asia include sweet potatoes, discoscorea, jackfruit seeds, buckwheat, taro, and tapioca (Fakhry, 2023). Others are Quinoa, lentils, arrowhead, gorgon fruit, sorghum, chickpea, proso millet, purple potatoes, quinoa grains, purple potatoes, banana fruit, amaranth, arrowhead, gorgon fruit, sorghum, chickpea, proso millet, and purple potatoes (Menegalli, 2016). These unconventional sources of starch have special qualities such as high Productivity, easily extractable starch, and functional Potential: Achira starch can serve as a substitute for chemically modified starches in food products1. as well as the potential to be used in a variety of sectors (Silveira and De Francisco, 2020).

Other numerous sources of starch for industrial use can be obtained from pearl millet grains and cowpea seeds and a couple of unusual sources (Azubuike *et al*., 2022). Plant sources include cellulose, glycoproteins, and proteins, which are rich sources of natural polymers like starch (Adigwe *et al*., 2022). Starch has been extracted from a wide variety of botanical sources, such as cereals, tubers, and roots. Common crop plants, such as rice, sweet potatoes, cassava, corn, and wheat, are also utilized as sources of starch. Furthermore, the starch content of novel sources such as fruits and medicinal plants is being investigated (Adewumi *et al*., 2019). Another possible source of starch for industrial uses is the tropical tree Artocarpus heterophyllus Lam (AHL). These diverse starch sources present possibilities for low-cost excipient synthesis for pharmaceutical formulations as well as sustainable economic development.

2.1 Tiger Nut Starch

Tiger nut is an excellent source of starch. The majority of cereal and tuber crops contain starch, which is mostly made up of the glucose polymers amylose and amylopectin (Akonor *et al*., 2019). Depending on the source, these polymers may be present in different amounts. Over Seventy percent of the calories consumed by humans come from starch, which is the primary reserve material in higher plants. Starch is a polysaccharide made up of D-glucose units joined by α-1,4 bonds and repeating units of D-glucopyranose. According to Costa *et al*. (2018), native starch is usually known to consist of up to 25 % amylose and 75 % amylopectin. While amylopectin is substantially thicker due to its strong branching, amylose is typically linear with glucose units connected by alpha-1,4 glycosidic linkages. In the end, these two molecules explain how starches behave in food systems (Akonor *et al*., 2019; Azeh *et al*., 2018).

Tiger nut starch has an off-white, white colour and no smell. According to Builders *et al*. (2013), its flow characteristics are similar to those of potato and maize starch. This implies that tiger nut starch has good physical properties and hence a significant deal of potential for usage in a broad range of applications. Unfortunately, little research has been reported on the characteristics of starch found in the tuber. This limits the use of tiger nut starch in the production of most industrial goods and food (Builders *et al*., 2013; Akonor *et al*., 2019).

Tiger nut starch is categorized as a C-type starch (Xiaofan *et al*., 2022; Xiaofan *et al*., 2022). C-type starch is a combination of A-type and B-type crystalline starch structures (Figure 1), and can be found in a variety of plant sources, including crops, rhizomes, and legumes.

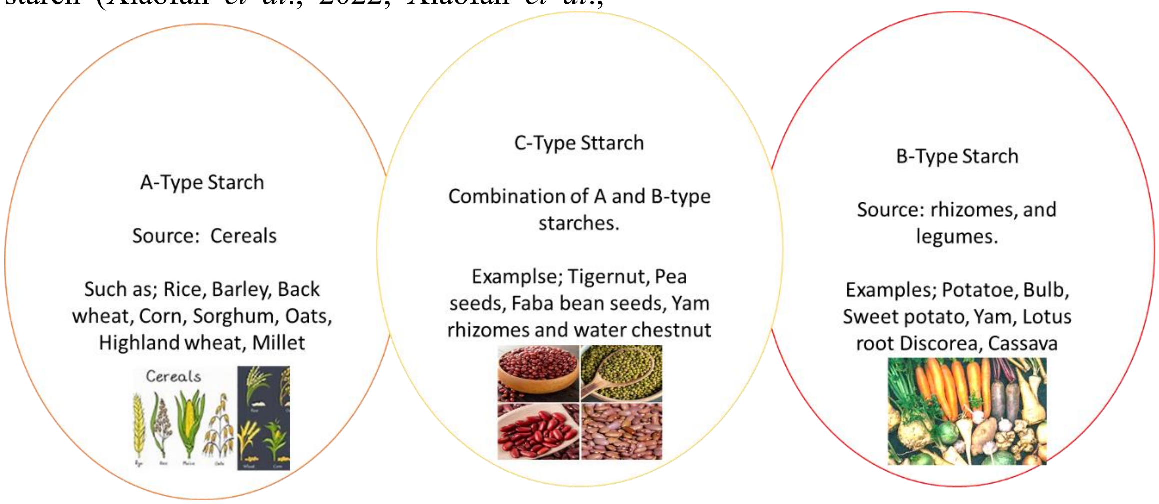

Fig.: 1: Showing the examples of the three categories of crystalline starch structure

C-type starches have particular crystal adjustability due to their distinct crystal structures, which combine both A- and B-type polymorphs (Yibo *et al*., 2022; Sabando *et al*., 2022). Starch has been known to be crystalline for many years. Starch can be divided into three primary groups, A, B, and C. Cereals are the main source of A-type starch, whereas B-type starch is mostly found in legumes and rhizome, and C-type in carbohydrates serves a variety of purposes. According to Zebin *et al*. (2017), C-type starch enhances the mechanical and physicochemical characteristics of starchy plant resources. Additionally, a significant amount of slowly digested and resistant starches are included in C-type starches, which are beneficial for the growth of gut microbiota and the glycemic response (Wei *et al*., 2010). Furthermore, starch granules' crystalline characteristics and structure are influenced by C-type starches, which have distinct crystal structures made up of both A- and B-type polymorphs (MacNeill *et al*., 2017). They serve as a source and a sink for carbon stocks and are also involved in the control of carbon allocation and metabolism in plants (Geiger *et al*., 2000). Starch in tissues and organs influences the accessibility of free sugars, which subsequently regulate processes related to development and growth (Bogracheva *et al*., 1998). Understanding C-type starches and their functions can help with future studies and possible industrial applications. In light of the aforementioned characteristics, C-type starches are appropriate for a range of uses, including but not limited to thickening, extending, and replacing fat in the food sector (Wei *et al*., 2017). Moreover, C-type starches can be utilized to fix shrinkage cracks in concrete constructions and for industrial applications. (Yashini *et al*., 2022). Finally, compared to maize or potato starch, C-type starches such as tiger nut starch display greater binding and compatibility characteristics (Li *et al*., 2017).

2.1.1 *Extraction of starch from tiger nut*

There are several techniques for extracting tiger nut starch (Figure 2): in situ hydrolysis with exogenous amylases, alkaline techniques, mechanical compression, and alkali extraction-acid precipitation (Yu *et al*., 2022; Zhang *et al*., 2022). By hydrolyzing the starch in the tuber, in situ hydrolysis with exogenous amylases from sprouting tiger nut tubers (Azeh *et al*., 2018).

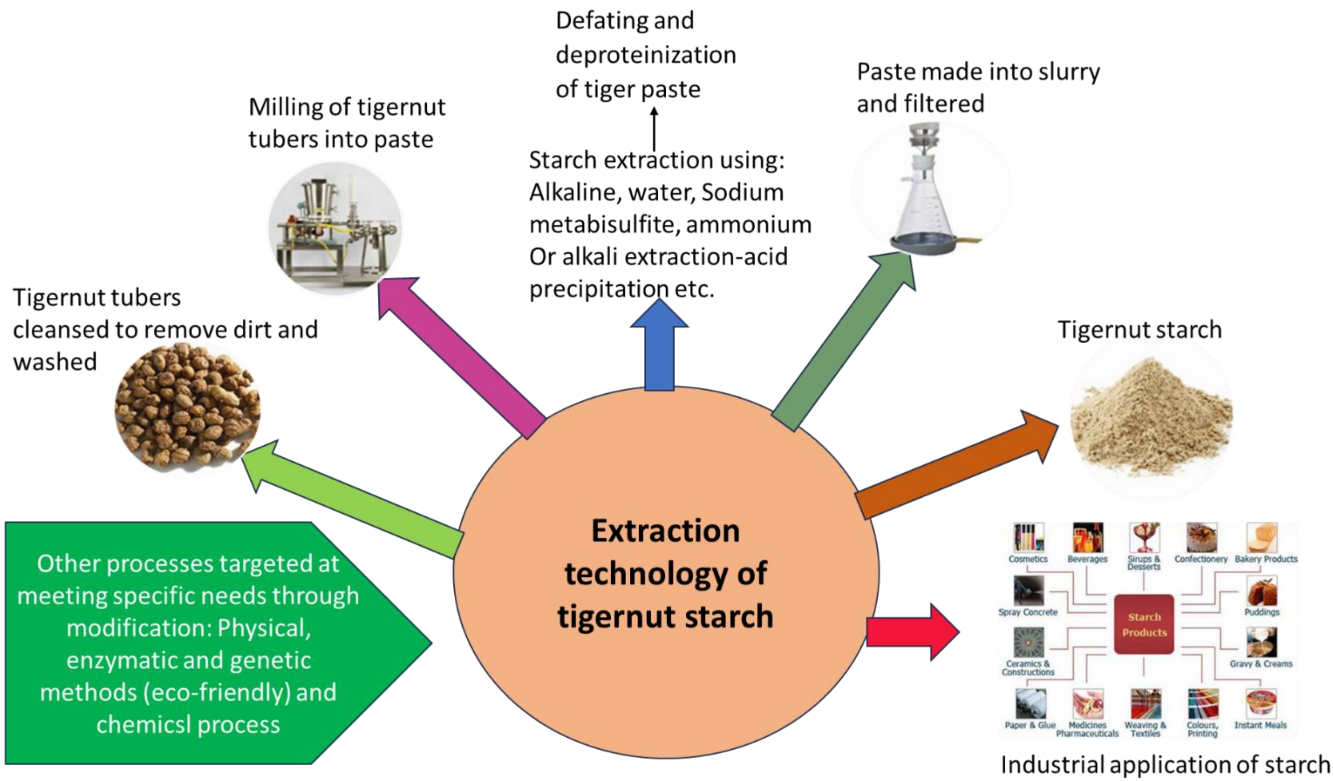

Fig. 2: Scheme showing starch extraction technology

2.1.1.1 *Alkaline method of starch extraction*

Tiger nut starch can be extracted using an alkaline technique. Proteins are extracted fromthe flour using diluted alkaline washing, and then the mixture is centrifuged to extract a precipitate. Following a distilled water wash, the precipitate is sieved through a screen. A NaCl solution is added to the mixture to wash the precipitate after centrifuging and collecting the supernatant. After adding methylbenzene, the liquid is shaken and allowed to stand for a while so that layers can form. After carefully removing the methylbenzene layer, the mixture is centrifuged once more to extract the liquid from the upper layer. High-purity starch is obtained by drying the precipitate after it has been cleaned of proteins and methylbenzene using anhydrous ethanol.

2.1.1.2 Extraction using Sodium metabisulfite extraction

Sodium metabisulfite is essential for starch extraction, according to research on tiger nut seeds and tubers (Hadiyat *et al*., 2023; Sunday, 2014). It improves the extracted starch's physicochemical characteristics, producing a high-purity, crystalline, bright white powder that is non-hygroscopic (Costa *et al*., 2017). Tigernut tubers' starch composition is also altered by immersing them in sodium metabisulfite, which enhances their physicochemical characteristics and performance (Xiaofan *et al*., 2022). Tigernut starch's structural and physicochemical qualities are further improved by cross-linking it with sodium trimetaphosphate. These attributes include better syneresis, freeze-thaw stability, and thermal stability. Overall, the quality and extraction of tiger nut starch are improved by the use of sodium metabisulfite, which makes it a viable biomaterial for a range of industrial uses. The starch's swelling power, gelatinization temperature, and solubility % are usually obtained at 90 °C. (Hidayat *et al*., 2023; Miao *et al*., 2021).

2.1.1.3 Extraction using water extraction method

Water plays a pivotal role in tiger nut starch extraction. Starch can be found in tiger nut tubers, and starch is extracted can affect its physicochemical characteristics. Different extraction techniques may have an impact on the nutritional and functional characteristics of tiger nut components, according to research (Wen-Bo *et al*., 2021). Tiger nut tubers are first ground up and then boiled in water for a predetermined period as part of the extraction process. The black cultivar, is milled for 23.8 minutes, boiled for 240 minutes, and has a tuber-to-water ratio of 1 g:7.8 ml. Conversely, the brown cultivar is boiled for 10 minutes with tuber to water ratio of 1 g:7.2 ml, and a grinding time of 22.0 minutes (Ezeh, 2016). For the black tubers, the anticipated milk solids output is 65.07 %, and for the brown tubers, it is 74.84 % using the same conditions (Sunday *et al*., 2014).

2.1.1.4 Extraction using alkali extraction-acid precipitation method

This process involves the soaking of the tiger nut in an alkali solution and then centrifuging it to yield crude starch milk. To create pure starch milk, the crude starch milk is first cleaned with acid and tap water. This pure starch milk is then dried to create the final starch product (Yu *et al*., 2022). Tiger nut starch is produced in the food industry using the alkali extraction-acid precipitation process, which is thought to be appropriate (Builders *et al*., 2013). The nutritional and functional qualities of the starch may be impacted by this process (Sunday *et al*., 2014). This technique is among the most suited for producing tiger nut starch for the food industry (Djomdi *et al*., 2020).

2.1.1.5 Extraction using ammonium precipitation method

To extract starch, choose a starchy source (such as grains or tubers). Collect the precipitated starch by filtration or centrifugation. Wash the starch with water to remove impurities. Dry the recovered starch to remove excess moisture. Store the starch in a cool, dry place. (Yu *et al*., 2022; Tessema and Admassu, 2021; Deepa and Vijayakumar, 2013; Kundu *et al*., 2011). With a yield of roughly 21.0 %, the extracted starch is usually crystalline, bright white, non-hygroscopic powder (Jonas *et al*., 2018). At 90 °C, the starch has a swelling capacity of 13.7 and a solubility of 2.36 % (Sunday *et al*., 2014). The starch has a gelatinization temperature of 66 °C (Miao *et al*., 2021). With a 28.0 % amylose concentration and a 72.0 % amylopectin content, the starch has a high purity rate (Djomdi *et al*., 2020). Its considerable potential for industrial applications has been reported, encompassing its use as biomaterials in the culinary, pharmaceutical, textile, and composites industries (Adewale *et al*., 2022; Rhowell *et al*., 2021).

2.1.1.6 Extraction using reverse micelle extraction method of Docusate sodium/isooctane

The reverse micelle extraction method of Docusate sodium/isooctane can be utilized to extract starch from tiger nuts. The hydrophobic starch in the reverse micelle system has a substitution degree of between 0.5 and 3.0 and is combined with a nonpolar organic solvent. Isooctane and n-octanol are present in the nonpolar organic solvent in a volume ratio of 1:1 to 9:1. The hydrophobic starch and the nonpolar organic solvent have a mass-volume ratio of 0.001:1 to 0.01:1. In comparison to previous reverse micelle systems, it has been discovered that this one has a greater extraction ratio for macromolecular proteins (Miao *et al*., 2021).

2.1.1.7 Overview of the extraction methods

Depending on the particular starch supply and required qualities, several industrial methods can be more or less effective for extracting starch. Numerous studies have investigated a variety of techniques. For instance, the process of extracting starch from Vidarikand tuber has produced encouraging outcomes for use in industry (Navinchandra *et al*., 2022). However, compared to conventional water extraction techniques, it has been discovered that the application of lactic acid bacteria fermentation, particularly back-slopping fermentation, greatly improves the quality of extracted common vetch starch (Zhao *et al*., 2020). Furthermore, a physical extraction method for longan kernel starch has been devised, providing a high starch yield in an easy, quick, economical, and eco-friendly process. Thus, parameters like yield, purity, environmental impact, and specialized application should be taken into account while selecting the optimal industrial method for starch extraction.

3.0 Modification of Starch

For most industrial uses, native starches are inappropriate due to their weak resilience to harsh processing conditions such as high temperature and shear, which are commonly encountered in the industry; starches in their native form, have limited application (Oyeyinka *et al*., 2021). Thankfully, there are a variety of modification techniques available to address these inherent flaws. Thus, starches are modified to circumvent such drawbacks and improve their suitability for a range of industrial uses (Yang *et al*., 2017).

The term "starch modification" describes the process of changing starch's composition and characteristics via enzymatic, chemical, physical, and genetic techniques or combinations of these techniques (Oyeyinka *et al*., 2021). These modifications are made to improve the properties of starch, and the way starch functions and is used in a variety of industries, including the food, pharmaceutical, and textile industries. Hydrothermal treatment, microwave, ball milling, ultrasonication, pulsed electric field, radiation, high hydrostatic pressure, and supercritical CO_2 treatment are examples of physical modifications of starch (He *et al*., 2023; Wang *et al*., 2023; Zhou *et al*., 2023; Bensaad *et al*., (2022). Through esterification and oxidation processes, and citric acid treatment of starch, new functional groups are added to starch molecules through chemical modification that enhances the physicochemical and functional characteristics of starch (Nuswantari, 2022). While genetic modification entails changing the genes involved in starch synthesis, enzymatic modifications use enzymes to break down or modify starch molecules (Ajay, 2023). With these changes, the structure and characteristics of starch can be optimized for certain uses, like decreasing the glycemic response and enhancing nutritional functionality (Ovando-Martínez and Simsek, 2022). The ability to modify starch is essential for increasing the number of uses for starch-based products and enhancing their functionality across a wide range of industries.

Additionally, it has been demonstrated that cutting-edge food processing methods like cold plasma, ozone, ultrasonication, microwave heating, high-pressure processing, pulsed electric fields, and enzymatic treatments greatly enhance the mechanical and rheological characteristics of starch-based materials for 3D printing (Saqib *et al*., 2023; Jiang *et al*., 2019).

3.1 Chemical modification of starch

Processes like esterification, oxidation, etherification, acetylation, acid modification, cationic linking, cross-linking, and genetic modification can all be used to chemically modify starch (Rostamabadi *et al*., 2023). These techniques frequently result in the addition of functional groups to the starch molecules, altering their physicochemical and functional characteristics (Omoregie Egharevba, 2020).

The tiger nut starch is greatly impacted by the method of chemical modification chosen. The characteristics of starch are changed by chemical processes like cross-linking with sodium trimetaphosphate (Sinhmar *et al*., 2023). When compared to the natural form, these alterations result in improved syneresis, decreased solubility, increased crystallinity, and improved freeze-thaw stability for tiger nut starch (Xiaofan *et al*., 2022). Additionally, chemical modification of tiger nut starch with octenyl succinic anhydride has been studied, revealing increased resistance to temperature (occurring at 67.52 °C) indicating its industrial potential and alterations in gelatinization behavior (Mohamed *et al*., 2021; Costa *et al*., 2018). Furthermore, the structure and characteristics of the starch granules are altered by chemical changes that add functional groups to them (Xiaofan *et al*., 2022). Superior pasting temperature, peak viscosity, thermal stability, and ease of regeneration at low temperatures are all displayed by the modified tiger nut starch (Nawaz *et al*., 2020). These alterations demonstrate how chemical modification can improve the overall quality and physical properties of tiger nut starch for a range of industrial uses (Costa *et al*., 2018). Also, chemical modification enhances swelling power and is inversely related to solubility, but heat moisture treatment (HMT) modification can result in decreased swelling power and solubility. These differences may affect how well starch performs in specific applications.

However, there are drawbacks to chemical modification that are not advantageous to humans, posing possible negative effects on health such as toxicity and allergies by using high concentrations of chemicals. (Kumari and Sit, 2023; Bensaad *et al*., 2022). Additionally, because it produces toxicity for both humans and the environment (Mollega *et al*., 2011), physical approaches to starch modification have been developed as a result (Bensaad *et al*., 2022).

It is vital to explore new methods that will help to overcome the drawbacks of the current approaches to starch modification. The continual creation of new items suggests that methods used to modify starches are also changing. Despite these obstacles, chemical starch modification is still a viable strategy for growing its uses across a range of industries and creating customized starches with distinctive qualities (Lemos *et al*., 2021).

3.2 Physical modification of starch

In the food sector, the physical modification of starch has many benefits. It satisfies consumer desire for more naturally occurring food ingredients by enabling the improvement of starch qualities without the need for chemical changes (Rostamabadi *et al*., 2023). Tigernut starch's physical structure is greatly impacted by the physical starch modification techniques used. The functional qualities of tigernut starch can be affected by physical processing methods such as cold plasma, high hydrostatic pressure, and microwave treatments, which can change the starch's morphology, crystallinity, and molecular structure (Xiaofan *et al*., 2022.) As an illustration, the starch structure of Tartary buckwheat was significantly impacted by the electron beam irradiation (EBI) treatment, as evidenced by changes in colour, thermal stability, crystal structure, and particle characteristics (Sinhmar *et al*., 2023). Tigernut starch that had undergone cross-linking also showed signs of structural changes brought about by the treatment, including increased crystallinity, improved freeze-thaw stability, and changed solubility and swelling power (Huang *et al*., 2023). These results demonstrate how various techniques of physical modification might impact the tiger nut starch's physical structure, hence influencing its qualities and uses.

The disadvantages of the physical modification of starch include limited application, excessive retrogradability, and low stability against harsh processing conditions (Rostamabadi *et al*., 2023). On the other hand, without the need for chemical reagents, physical modification techniques provide advantages such as modifications to the chemical structure and molecular makeup of starch (Sinhmar *et al*., 2022).

3.3 Genetic modification of starch

The possibility of enhancing starch utilization through genetic modification has been investigated (Yuyue *et al*., 2022). The process of modifying starch's characteristics through genetic engineering is known as genetic starch modification. The process entails modifying the expression of genes linked to starch metabolism to generate starches that exhibit specific properties. For certain uses, such as enhancing paste clarity, freeze-thaw stability, and digestibility, starch's functionality can be improved through genetic alteration (He *et al*., 2023; Bensaad *et al*., 2022; Ovando-Martínez and Simsek, 2022). It provides a sustainable and environmentally friendly method of starch modification that may have positive effects on the economy and environment (Xu, 2016). Techniques for genetic modification include expressing 4, 6-α-glucanotransferase to change the shape of starch granules, adding enzymes to change the starch phosphate content and polysaccharide structure, and silencing RNA to create waxy starch with better qualities. Starch can be modified genetically to match the unique requirements of different industries, which resulted in the development of starch-based goods with optimum qualities and targeted architectures.

Genetic modification of starch has various benefits, for example, it makes it possible to increase wheat's resistant starch content, which is very important from a commercial standpoint (Irshad *et al*., 2022). Additionally, it permits starch to be modified to enhance its nutritional value and lower its glycemic response, improving its suitability for particular diets. Furthermore, high-amylose wheat with higher protein and resistant starch contents as well as other beneficial characteristics can be produced through genetic modification (Li *et al*., 2021).

Additionally, the development of genetic technologies has made it possible to specifically manipulate the genes involved in starch production, changing the composition of starch and possibly other starch properties (Chen *et al*., 2021). Starch genetic modification has been investigated in several research. For instance, Li *et al*. (2017), created high-amylose wheat cultivars with higher resistant starch content by targeting mutagenesis of the TaSBEIIa gene in wheat using CRISPR/Cas9 technology (Bensaad *et al*., 2022). Similar to this, Chen *et al*. (2014), studied how crops' starch biosynthesis genes can be changed via gene editing techniques, changing the starch's composition as well as other characteristics (He *et al*., 2023). Chen *et al*. (2021) also highlighted genetic alteration as a possible starch modification technique, emphasizing its capacity to enhance the consumption of starch. Starch genetic modification offers a green technology method that could result in starches with unique qualities, enhancing their functionality and broadening their uses across a range of industries (Li *et al*., 2021).

Tigernut starch synthesis through genetic modification has both possible advantages and disadvantages. Enhancing functional qualities and industrial potential (Yu *et al*., 2022), enhancing physicochemical qualities for tablet manufacturing (Costa *et al*., 2018), and raising retrogradation propensity for improved gel properties (Awolu *et al*., 2017) are some advantages. Nevertheless, disadvantages can include changes in the nutritional makeup and bioactive components, which might have an impact on the tiger nuts capacity to scavenge radicals and their therapeutic qualities (Builders *et al*., 2013). Furthermore, genetic mutation may result in modifications to the structure and properties of starch, which may affect features such as the temperature at which gelatinization occurs and its molecular makeup (Lv *et al*., 2022). All things considered, genetic modification can improve some features of tigernut starch, but preserving the advantageous qualities of this priceless crop will require careful assessment of its effects on nutritional and functional traits.

3.4` Enzymatic modification of starch

Enzymatic starch modification is the process of modifying starch's characteristics with the aid of enzymes. This plays a crucial role in improving the properties of native starch and helping to overcome its limitations for a variety of uses. The enzymatic alteration of starch presents numerous benefits. Firstly, it is a perfect green modification approach because it works well in mild settings and has great substrate selectivity and product safety (Mohamed *et al*., 2021). Use of enzymes including α-amylase, β-amylase, glucoamylase, isoamylase, and pullulanase can accomplish enzymatic modification (Sneh *et al*., 2022). These enzymes have the ability to alter starch's granular shape, crystalline type, paste characteristics, swelling power, and solubility (Mohamed *et al*., 2021; He *et al*., 2022). Different methods and enzymes can be utilized for granular and gelatinized starch systems when modifying them enzymatically (Zhu *et al*., 2023). The efficient and economical conversion of starch-based solid wastes can also be achieved through enzymatic starch modification.

Natural starch's low water-holding ability, syneresis, and retrogradation can be overcome by enzymatic modification, which expands its potential industrial uses (He *et al*., 2022). Additionally, it can modify the characteristics of starch by changing its molecular mass, branch chain-length distribution, and amylose/amylopectin ratio (Yuyue *et al*., 2022). Enzymatic starch modification can improve its functioning, such as retarding retrogradation during storage and improving the gels' capacity to withstand freeze-thaw cycles (Sneh *et al*., 2022).

Additionally, the food sector has researched the potential uses of enzymatic modification of starch, including food ingredients, product quality enhancement, and increased food processing efficiency (Ren *et al*., 2018). All things considered, enzymatic starch modification provides a secure, effective, and adaptable method to enhance its qualities and broaden its uses. Furthermore, enzymatic modification is a perfect green modification approach because it has several advantages over chemical and physical procedures, including moderate conditions, excellent substrate selectivity, and good product safety (Yuyue *et al*., 2022).

Numerous enzymes, including α-amylase, β-amylase, glucoamylase, isoamylase, and pullulanase, are involved in the modification of tiger nut starch and are essential in changing its characteristics (Mohamed *et al*., 2021). Enzymatic modification of tiger nut starch is superior to other modification methods in terms of production, cost, and environmental effects. The enzymatic modification offers an effective and environmentally friendly strategy, especially when using α-amylase and glucoamylase (He *et al*., 2023). This method can improve the physicochemical characteristics of starch and enable the development of resistant starch, which is vital for health (Campbell-Duruflé, 2023). Furthermore, starch solid wastes can be effectively hydrolyzed by enzymatic methods, which lower treatment costs and have superior environmental and biosafety qualities (Zhu *et al*., 2023; Zhong *et al*., 2022). When it comes to starch waste treatment, enzymatic modification can drastically save costs and increase efficiency when compared to conventional immobilization techniques. All things considered, tiger nut starch enzymatic modification is a viable and efficient method that has favourable effects on production, economy, and environmental sustainability.

4.0 Applications of tiger nut starch

Tiger nut starch is used in different ways (Figure 3). It can be used to make steamed bread, which improves the bread's chewiness and crumb structure (Xiaofan *et al*., 2022). It is advised to employ tiger nuts and their byproducts, such as starch, in baked goods and related dishes (Abdullahi *et al*., 2022; Gasparre *et al*., 2020). Tiger nut starch has the potential to save production costs and enhance product quality when used as an additive in brewing (Francis and Umeh, 2021). Tiger nut starch can also be utilized in the production of gluten-free snacks, as it helps to prevent starch from excessive degradation during extrusion and increases the snack's texture, protein and ash content, and overall antioxidant activity (Miao *et al*., 2021). Furthermore, tiger nut starch can be utilized to make tiger nut milk, in which the milk yields and sweetness are enhanced without raising viscosity through the in situ hydrolysis of starch utilizing exogenous amylases (Gasparre *et al*., 2020). The physicochemical features of tiger nut starch, such as its enhanced solubility, swelling power, syneresis, freeze-thaw stability, and thermal stability, can be further improved by cross-linking it (Lv *et al*., 2022). Summarily; tiger nut starch provides a number of advantages for a variety of food sector applications.

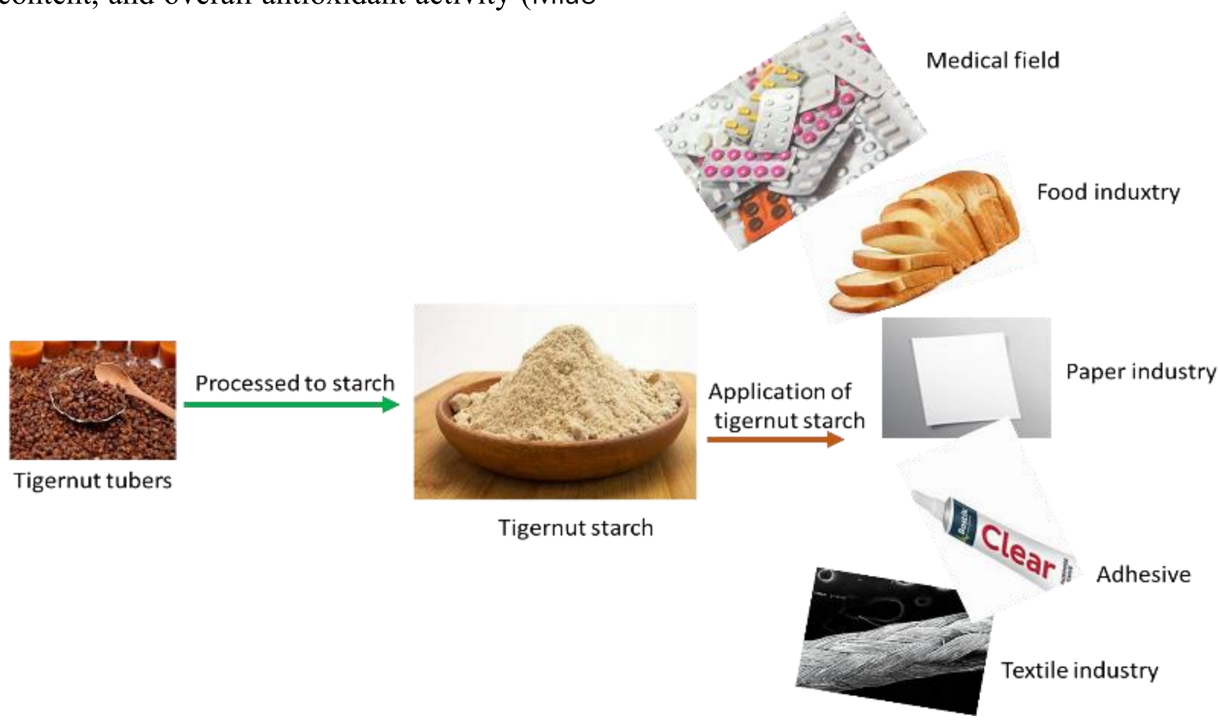

Fig. 3: Showing various fields of application of tiger nut starch

5.0 Conclusion

Based on the above review, the following findings were observed.

(i) Tiger nut starch exhibits distinct molecular structures and properties.
(ii) Its fine granule size and A-type crystallinity contribute to its functional characteristics.
(iii) Tiger nut starch can be modified using physical, chemical, enzymatic, and dual methods.
(iv) It holds promise in both food and pharmaceutical industries.
(v) As a vehicle for delivering chemicals, it can enhance product quality.
(vi) Sustainable utilization of tiger nut by-products, including starch, is crucial.
(vii) Further research and development are needed to unlock its full potential.

Tiger nut starch, derived from the tubers of *Cyperus esculentus*, possesses unique properties that set it apart from conventional starches. Its gel consistency, retrogradation propensity, and freeze-thaw stability make it a promising resource for various applications. However, despite its potential, tiger nut starch remains underutilized due to limited knowledge of its industrial capabilities.

The following recommendations are hereby made,

(i) Invest in research to explore tiger nut starch properties further.
(ii) Investigate novel applications beyond food and pharmaceuticals.
(iii) Collaborate with food and pharmaceutical industries to develop innovative products.
(iv) Promote awareness of tiger nut starch as a valuable resource.
(v) Educate farmers, processors, and consumers about tiger nut starch.
(vi) Highlight its sustainable aspects and economic benefits

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Compliance with Ethical Standards Declarations

The authors declare that they have no conflict of interest.

Data availability

All data used in this study will be readily available to the public.

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data public.

Competing interests

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