Chapter 1

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1.1 Background of the work

Due to the rapid growth of the world's population, which is expected to be 9.7 billion people in the next 30 years **[14]**, it will be a difficult task to produce enough food to feed everyone **[64]**. Political and social unrest will emerge if people lack access to enough nutritious food to maintain active and healthy lifestyles, as a result, food security is expected to become a serious issue. Consequently, it is more likely that the demand for quantity of food cannot be resolved merely by making improvements to the mainstay food crops. It is believed that many countries are getting close to their maximum yield capacity of food production. To ensure food security, research must be carried out on the currently underutilized crops, such as yams **[64]**.

The genus *Dioscorea* is an herbaceous, woody, and climber plant with underground tubers. Species of the genus *Dioscorea* are commonly referred to as 'yams' and only about a hundred species are edible either as such or after detoxification and long or quick cooking. From 12.4 million tonnes in 1972 to 75.1 million tonnes in 2021, the global yam production expanded at an average yearly rate of 4.07% **[31]**. Production of yam in India was 733000 metric ton during 2015-2016 **[42]**. In many regions where yams are grown, yam farming is recognized as a source of food security and employment for many people **[70]**. In West African nations like Nigeria, Cote D'Ivoire, Ghana, Benin, and Togo, yam is one of the chief cash and food crops. Despite significant production costs and market price swings, its cultivation is quite profitable and accounts for more than 60% of people's principal source of income **[75]**. Yams, a labor-intensive and weed-sensitive food crop, require a lot of care to grow and heed of farmers throughout the year to oversee the production process **[75]**. There is a lack of research on the utilization of yams as a food and cash crop despite their high food and market values, higher yield potential, and range of post-harvest storage and use options **[6]**. It is possible to prevent food insecurity, accomplish sustainable development objectives, and intensify agricultural practices in developing countries like India taking into account these crop qualities.

Although different species are available, specifically *D. alata* and *D. cayennensis* are the staple crops for more than 100 million people, particularly in Western Africa **[40]**. Of the 50 species of *Dioscorea* found in India, about 19 are known to occur only in Assam **[20]**. **Sharma and Hore [60]** reported 28 species and 25 cultivars of the genus *Dioscorea* in northeastern India. In recent decades, this genus has emerged as one of the most important sources of diosgenin, a plant sapogenin used in the pharmaceutical industries for the synthesis of steroid drugs **[33, 74]**. However, starch, which is the most abundant carbohydrate in the rhizomes of different *Dioscorea* species, is always neglected and discarded during the isolation of small bioactive molecules, resulting in a significant waste of the valuable resource. Although the starch content of *Dioscorea* species can be up to 80 % on a dry weight basis **[45]**, research on the food applications of the yam flours and starches is limited.

Health-conscious consumers are no longer interested in snacks for enjoyment alone, and the demand for nutritious and healthy disease-preventing snacks has risen over the years. Debarring of gluten from the diet is the only treatment for celiac disease, so there has been a growing interest in substituting or replacing wheat flour with gluten-free formulations made from refined gluten-free flour, starch, and hydrocolloids **[22, 34]**. Gluten is a protein present in most cereals, and based on the proportion of the proteins present in the flours, it shows different behavior, such as glutenins are mainly responsible for elasticity and cohesion, and gliadins provide fluidity, extensibility, and expansion properties **[44]**. Several alternative flours from cereals such as rice, sorghum, corn, and teff **[22, 44]**; pseudocereals such as amaranth, quinoa, soya, and buckwheat **[16, 22, 44, 69, 71]**; and seeds such as linseed, sesame, and chia **[27, 44, 65]** that have none or little of these gluten-forming proteins have been studied.

Yam flour, used as a replacement or partial substitution for wheat flour or other flour, has also been used to fabricate several products such as bread **[24, 36, 37, 67]**, salted noodles **[35]**, extruded products **[59]**, amala paste **[38]**, pasta **[29]**, expanded extrudates **[30]**, cookies **[48]**, crackers **[57]**, etc. Although yam flour is rich in starch and used as an ingredient in various food products, yam flour alone is not suitable for the development of dough as the flour is gluten-free. Therefore, to get the qualities of gluten in gluten-free food, protein from other sources are typically added to the flour. Various blends of gluten-free flour and proteins have been examined to develop several products, for example, products such as cookies from blends of rice flour and soy protein isolate **[47]**, blends of maize flour and soy protein isolate **[2]**, blends of rice flour and soy protein isolate/whey protein concentrate **[58]**; bread from blends of rice flour and whey protein concentrate/soy protein isolate **[63]**, blends of rice flour and rice bran protein concentrate/egg albumin **[53]**; pasta from blends of pearl millet flour and sodium caseinate alone or in combination with whey protein concentrate **[32]**; muffins from blends of rice flour and cowpea protein isolate **[61]**; sponge cake from blends of rice flour and whey protein concentrate **[4]**; pasta from blends of rice flour and whey protein concentrate **[52]**; etc. Hence, yam flour substituted with protein isolate or concentrate can also be utilized and checked for the development of gluten-free products.

The main ingredient in yams is starch (65.2–76.6% dry basis), which can be a rich source of carbohydrates and has a variety of uses in the food processing industries **[78]**. Yams also can serve as substitute sources of commercial starch, so in-depth understanding of their functional characteristics is necessary to maximize their potential for usage in both culinary and non-food applications **[3, 55]**. Few studies have been published on yam starch's particle morphology, crystal type, pasting qualities, in vitro digestibility, and rheological dynamics **[25]**. However, native starch has some drawbacks that restrict its use in the food industry, which include low solubility in water, low shear resistance, a higher tendency to retrograde, poor processability, lower mechanical strength, less process tolerance under higher stress conditions such as shear forces, higher digestibility, high viscosity, and low thermal stability **[25, 55, 66]**. Therefore, the characteristics of yam starch needs to be improved to boost its industrial usability.

Physical, chemical, and enzymatic are the three types of modifications often applied to alter the characteristics of starches due to their efficacy and low cost. Meanwhile, neither physical nor chemical techniques have received much attention **[19, 66]**. The physical modification includes modifications such as hydrothermal treatment **[8, 9]** mainly heat and moisture treatment (HMT) **[1, 66, 77]** and annealing (ANN) **[1, 17, 77]**; irradiation **[72]**; drying and blanching **[12, 13, 15]**; ultrasonication **[11, 41]**; high-pressure processing **[73]**; cooking-steaming, boiling and microwave **[18]**; blanching and soaking **[56]**, etc. The chemical modification of yam polysaccharides includes modifications such as acetylation **[55]**; phosphorylation, selenide functionalization, and carboxymethylation **[76]**; acid hydrolysis **[17, 46]**; sulfation **[26]**; and chemical methods such as esterification, crosslinking, etherification, etc. **[55]**. Moreover, new functional groups are added to the starch molecule to broaden the variety of uses for the substance. The modifications can affect the molecular size and particle characteristics, resulting in starch with unique features **[25, 55]**. Enzymatic starch modification is a flexible method that uses specialized enzymes to modify the structure and properties of starch molecules **[7]**. Amylases hydrolyzes starch to produce smaller components such as maltose and dextrins by targeting α-1,4-glycosidic bonds **[23, 39]**. Debranching enzymes which includes isoamylase and pullulanase hydrolyzes the α-1,6-glycosidic bonds of amylopectin **[23]**. Transferases break the α-1-4 glycosidic linkage in a donor molecule and move a portion of the donor molecule to a glycosidic acceptor, creating a new glycosidic bond in the process **[23]**. Traditionally, enzymes have been employed to alter the properties of native starches, resulting in products with modified solubility, viscosity, and/or gelation characteristics **[54]**.

Starch modifications are mostly done to enhance the viscosity, processing parameters, shelf stability, textural properties, particle integrity, appearance, solubility, workability, and emulsification properties in order to utilize them more effectively in the food, cosmetics, and pharmaceutical industries **[17]**. Recently, a number of studies to modify the properties of yam starches such as the digestibility (resistant starch such as RS3, RS4) **[11]**, water and oil holding capacity **[17]**, viscosity **[28]**, textural characteristics **[55]**, solubility **[55]**, swelling properties **[55]**, morphology **[17]**, foam stability and emulsification properties **[55]**, densities **[17]**, flowability/flowing properties **[55]**, particles size **[8]**, etc., have been conducted.

Starches from yams, both natural and processed, have a variety of uses in food industries. The native yam starch that looks extremely pale in color might make it ideal for application in ice creams, concentrated liquids and sweets. Additionally, it is utilized in goods that require high processing temperatures such as canned foods, crunchy foods, salad dressings, and ready-made sweets, due to the reduced gelatinization temperature and superior thermal stability against freezing and thawing cycles **[49]**. Yam starch can also be employed in ready-to-eat desserts, salad dressings, and crispy foods due to its high amylopectin content **[78]**. Apart from yam starch in its natural state, yam starch-based foods with high nutritional values and low digestibility can also be prepared by applying a variety of physical modifications (HMT, ANN, etc.) and chemical modifications to the native starch. In addition, these products can be a possible substrate for the bakery industries. Foods made with physically modified starch are more convenient to consume by individuals with diabetes and obesity **[10]**. Cross-linked starch can be employed as a texturizer in sauces, soups, and gravies because of its better stability against swelling, high temperatures, and strong shear. Esterified starches, such as OSA starch, can be used to thicken and stabilize the emulsions **[62]**. Yam starch has been utilized to create biodegradable edible films, apart from being used as culinary ingredients **[43, 51]**. In a study to create biodegradable films, yam starches were chemically modified (oxidized, cross-linked, and dual: oxidized and cross-linked) which had a substantial impact on the film's qualities **[43]**.

Yam flours and starches are comparatively underutilized and underexploited in contrast to the flours and starches from other tubers, roots, cereals, fruits, and even legumes. Lack of adequate information on the structure, function, and potential application of the starches is one of the limiting factors for the industrial application of yam starches **[50, 68, 78]**. The physicochemical, functional, and pasting qualities of flours and starches from cultivated *Dioscorea* species of northeast India are yet to be thoroughly studied. Meanwhile, there are no reports on the comparative study of HMT and ANN treatments on yam starch, and the effect of moisture levels during these treatments on yam starch. Similarly, reports on hydroxypropylated and cross-linked yam starch are very few, which limits its application **[5, 21]**. Therefore, a study was designed to investigate the quality of flours and starches from the underutilized yam cultivars of Assam. In this study, yam flour and almond protein isolate blends were used in the preparation of gluten-free cookies, and a quality assessment of the prepared cookies was done. Moreover, the effect of physical and chemical modifications on the functional, thermal, pasting, crystalline, morphological, and rheological properties of underutilized yam starches was investigated, and the suitability of native as well as hydrothermally treated starches for developing edible films was checked.

1.2 Objectives

To complete the research work of the study, the objectives that were proposed are as follows:

Objective 1: To characterize the flours of selected *Dioscorea* species and its utilization in cookies

Objective 2: To characterize the starch isolated from the selected *Dioscorea* species for physicochemical and functional properties

Objective 3: To analyze the properties of physically modified starches of selected *Dioscorea* species

Objective 4: To analyze the properties of chemically modified starches of selected *Dioscorea* species

Objective 5: To develop edible film/coating from the native and physically modified *Dioscorea* starches

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