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Comparative Studies on the Production of Glucose and High Fructose Syrup from Tuber Starches

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Abstract

Glucose and high fructose syrup (HFS) are made extensively from corn starch and the high cost of production demands the lookout for alternative starches as raw material. The present study was to compare the potential of tuber starches such as arrowroot, cassava, Curcuma, Dioscorea, sweet potato and Xanthosoma with corn starch for HFS production. The process consisted of liquefaction followed by saccharification and isomerization using three enzymes such as Liquezyme, Dextrozyme and Sweetzyme respectively. High performance liquid chromatographic (HPLC) profile showed that the starch conversion to glucose for the starches was equivalent or superior to that for corn starch. Sugar profile of the saccharified slurry had a composition of 98.28 to 98.84% glucose, maltose (1.03 to 1.69%) and maltotriose (0.03 to 0.10%) for arrowroot, Curcuma and cassava, while a lower range of glucose (94.76-97.28%) and higher range of maltose and maltotriose (2.0-4.3% and 0.49-0.75% respectively) for the other starches. Percentage conversion to fructose as well as fructose yield (g/100g starch) was the highest for arrowroot and Curcuma starches. Tuber starches offer promise as substitute for corn starch in the production of glucose and high fructose syrup.

Keywords: Carbohydrate profile, glucose syrup, high fructose syrup, saccharification, tuber starches.

Introduction

Root and tuber crops along with corn (maize) supply most of starch in Asian markets. Globally, the major commodities from which starch is derived are corn, cassava, sweet potato, potato and wheat, with corn accounting for 37% of the starch production. In developing countries, root crops are relatively more important as sources of starch than cereal crops. Root crops account for 60 per cent of Asian starch production, especially cassava (29 per cent), sweet potato (26 per cent) and potato (5 per cent). Many industrial products such as modified starches, maltodextrins, high fructose syrup (HFS), glucose syrup, gums, adhesives, bioethanol etc. are made from starch[1-4]. The biggest user of starch worldwide is the sweetener industry. It can easily be hydrolyzed to form syrup containing dextrose, maltose and other oligosaccharides. The production of sugar syrups by enzymatic method is amongst the most advanced food technologies, characterized by higher yields, wide range of products, higher product quality and energy economy[5].

High fructose syrups (HFS) are widely employed as nutritional sweeteners because of its characteristics like noncrystalline nature, high sweetness, better solubility etc[6,7]. Corn starch is the raw material for high fructose syrup production in the US and in many other parts of the world[8]. However, alternative starch sources have been reported as potential raw materials in Europe, South America and Asia[9]. Production of hfs, glucose syrups and maltodextrins from nonconventional sources of starch, such as amaranth, cassava, potato, and sorghum has been reported[10-12]. There are several reports on the studies conducted to decrease the production costs and also to find a new and economically attractive starch source for glucose and fructose syrup production[13-15]. Studies were made by several workers to economise the production of HFS through synergistic action of α-amylase and glucoamylase on raw corn[16], using wet cassava and sweet potato root slurry as raw material instead of starch etc[17].

The main component of tuber crops is starch and thus acts as important source of starch. Except cassava and sweet potato, starch from other tuber crops has not been exploited industrially. Hence, literature on the exploitation of lesser known tuber starches for value addition is also scanty. This paper reports on a comparative study of various tuber starches for their potential use in the production of glucose and high fructose syrup.

Material and Methods

Tuber crops used for study were Arrowroot (*Maranta arundinacea*), Cassava (*Manihot esculenta* Crantz), *Curcuma (Curcuma zedoaria)*, greater yam (*Dioscorea alata)*, Sweet potato (*Ipomoea batatas*) and tannia (*Xanthosoma sagittifolium).* Starch of high quality and fine grade was prepared from tubers of optimum maturity, grown at the Institute farm. Starch was extracted from peeled tubers by the standard procedure, of wet blending (1.0 kg tuber slices in 5.0L water), allowing to setting for 18-24h, drying and sieving through 250 µ sieve to obtain fine powder. Commercial corn starch was purchased from M/s Sisco Research Laboratories, Mumbai, India.

Enzyme Sources: Liquezyme X (thermostable α- amylase; EC 3.2.1.1) derived from a genetically modified strain of *Bacillus licheniformis* with an activity of 200 kilo novo units (KNU) per gram and Dextrozyme GA (glucoamylase; EC 3.2.1.3) produced from a genetically modified strain of an *Aspergillus sp.* with an activity of 270 amyloglucosidase (AGU) units per gram were purchased from M/s Novozymes A/s, Denmark. Sweetzyme T (immobilized glucose isomerase; EC 5.3.1.5) with an activity of 350 IGIU per gram was purchased from M/s Novo Nordisk Biochem., USA.

Absolute starch content: The absolute starch content in the tuber starches and corn starch was estimated by the method of Moorthy and Padmaja[18]. The starch was hydrolysed using 2.0 N HCl at 100°C for 30 min and the released sugars were estimated titrimetrically against potassium ferricyanide, with methylene blue as indicator. Starch content was computed from the sugar values by multiplying with the Morris factor, 0.9. The absolute starch content was used for computing the percentage conversion of starch to reducing groups at the liquefaction stage and further to glucose at the saccharification stage.

Liquefaction of starch: A suspension of 20% (w/v) of previously extracted starch was prepared. The pH was adjusted to 7.0 and incubated in water bath (Julabo, SW21) at 90˚C with 0.1% (v/w) of commercial α-amylase (Liquezyme X) for one hour for liquefaction[19,20]. The reducing groups formed were estimated in aliquots (duplicate) by the Nelson- Somogyi method[21,22]. An aliquot of the properly diluted liquefied slurry was treated with alkaline copper reagent and heated in boiling water for 10 min. The cuprous oxide formed was treated with arsenomolybdate reagent to obtain the blue colored complex, whose absorbance was measured at 520 nm and the reducing sugars were calculated using D-glucose standard.

Saccharification of liquefied starch slurry: The liquefied slurry was cooled to 60°C and the pH was adjusted to 4.0. Dextrozyme GA (0.2% v/w) with an activity of 270 amyloglucosidase units/g was added and incubation continued for 48 h at 60°C[19,20]. The reducing groups formed were estimated by the Nelson- Somogyi method[21,22] as described earlier. The glucose content of the aliquots was also determined by the glucose oxidase- peroxidase method using the glucose (GO) assay kit (Sigma, Missouri, USA), which specifically assays glucose. The kit contained glucose oxidase- peroxidase reagent (product code G 3660), O-dianisidine reagent (product code D 2679) and glucose standard (product code G 3285)[23]. The glucose oxidase/peroxidase reagent was dissolved in 39.2 mL deionized water and stored in an amber bottle at 4˚C till use. The o-dianisidine reagent was reconstituted with 1.0 mL deionized water and stored under dark at 4˚C. The assay reagent was constituted by mixing 0.8 mL o-dianisidine reagent with 39.2 mL of GOD/POD reagent. Two milliliters of assay reagent were added to the test (aliquot of the diluted saccharified slurry; 1.0 ml) and standard samples (0.05 ml) and after incubating for 30 min at 37˚C, the reaction was stopped by adding 2.0 ml sulfuric acid (12.0 N) to each tube. The absorbance was read against a reagent blank at 540 nm.

The percentage conversion to reducing groups or glucose was computed using the formula

$$\text{Percentage conversion} = \frac{\text{Reducing sugar/glucose yield} \times 100}{\text{Starch (\% dwb)}} \quad (1)$$

High performance liquid chromatography (HPLC) Analysis of glucose syrups from various starches: The glucose syrup obtained after saccharification was characterized by Waters HPLC System (Ms.Waters India Pvt. Ltd., Bengaluru), with 600 Series Pump, in order to understand the sugar profile. The sugar syrup was filtered through a Millipore Microfilter (0.2μm) and the filtrate (20 μl) was injected using 7725 Rheodyne injector and carbohydrate separations were accomplished on a Waters u Bondapak – NH_2 column. The HPLC mobile phase consisted of a mixture of LC grade acetonitrile/H_2O (70/30 v/v) and the flow rate was 1.0 ml/min. Carbohydrates were detected by a 2414 RI detector. Samples were diluted ten times with HPLC grade water. The concentrations of reducing sugars (glucose, maltose, maltotriose) were obtained by comparison of peak areas of samples to those of standard sugar solutions of known concentration which were made from the sugar standards of M/s. Sigma, St Louis, USA.

Isomerization of glucose syrup: After the saccharification, the glucose syrup was filtered and concentrated to 40% (w/v) solids. $MgSO_4.7H_2O$ (16 mg) was added to this and the pH adjusted to 7.5 and kept in a thermostatic water bath at 60°C. After equilibration, 50 mg Sweetzyme T/g glucose with an activity of 350 IGIU/g was added. The incubation was continued at 60°C for 24 h. The fructose formed was estimated by the cysteine carbazole method[24]. An aliquot (1.0 mL) of the isomerized syrup (diluted 400 times) was treated with 0.2mL cysteine hydrochloride (1.5%), 6.0mL sulfuric acid (70%) and 0.2 mL carbazole reagent (0.12% w/v in alcohol) and incubated for 1.0 h at 37˚C. The absorbance of the colored product was measured against a reagent blank at 560nm and the fructose yield was calculated using D-fructose standard.

Statistical analysis: All experiments were replicated four times and duplicate analysis was performed on each replicate and the results were subjected to analysis of variance, ANOVA using the statistical software package GenStat[25]. Statistical analysis was done for all parameters using one way Analysis of Variance (ANOVA) for comparison of mean values among different treatments. Duncan's multiple range test was performed to determine any significant differences ($p < 0.05$) between different treatments. Each mean value was assigned with a superscript and the pair of mean values which contains the same alphabets in the superscript is not significantly different.

Abbreviations: HFS- High Fructose Syrup; HPLC-High Performance Liquid; chromatography; AGU-Amyloglucosidase Units; KNU-Kilo Novo Units; IGIU-Immobilized Glucose Isomerase Units; ANOVA-Analysis of Variance; DE-Dextrose Equivalent.

Results and Discussion

The extracted starch contains fibre, lipids, proteins and minerals, depending on a number of factors such as method of extraction, environmental conditions, age of the crop etc[26]. The absolute starch content of starch samples also varied depending on the extent of purity of starch (table 1). These values were used for computing the percentage conversion of starch to glucose. Several workers reported considerable variation in moisture content among tuber starches[27-29].

Table-1
Absolute starch content in Tuber starches

Starch	Absolute starch [%]
Arrowroot	94.08±0.57
Cassava	95.07±0.58
Curcuma sp.	92.15±0.54
Dioscorea sp.	92.79±0.96
Sweet potato	94.74±1.00
Xanthosoma sp.	95.07±0.58
Corn (maize)	93.10±0.56
L.S.D (5%)	1.239

$p < 0.001$; Mean ± SD from three replicates

Liquefaction of starches: The percentage conversion to reducing groups on absolute starch basis in all the tuber starches after liquefaction was 14-15% (w/w), which was comparable to that of corn starch (control) (table 2). Two factors that determine DE at the end of liquefaction are: i. dose of Liquezyme added and ii. duration (min) necessary for liquefaction. It was found that higher amounts of reducing groups were formed in arrowroot starch slurry (2.98 g) and cassava starch slurry (2.95g) compared to control as well as other tuber starches. Maximum percentage conversion to reducing groups occurred in arrowroot (15.82%) and *Curcuma* (15.73%) starch slurry. *Curcuma* starch was found to be easily digestible like arrowroot starch based on the *in vitro* α-amylase digestibility patterns[30]. Regy Johnson et al[19,20] reported the optimization of process parameters for enzyme catalyzed liquefaction and saccharification of cassava and sweet potato starch for HFS production.

Arasaratnam et al.[31] reported that α-amylase alone was sufficient for corn starch hydrolysis and obtained sugar syrups with high maltose concentration and reduced amounts of higher sugars, while others reported the need to use both liquefying and saccharifying enzymes[32,33].

Starch granules are dispersed or gelatinized in aqueous solution during liquefaction and then partially hydrolyzed by thermostable α-amylase. Souza and Andrade[34] reported that moist corn starch (40% moisture content) can be gelatinised thermally at 110°C. In the conventional liquefaction process, starch slurry is heated to 105°C in a jet cooker for 5 min. in the presence of α-amylase and after which the reaction mixture is cooled to 90–95°C in a holding tank to complete the liquefaction. Nevertheless, in our study, gelatinization and liquefaction of all the starches were done in a single heat treatment at 90°C after adding Liquezyme.

Table-2
Liquefaction of various tuber starches vis-à-vis corn starch

Source of starch	Amount of reducing sugar formed [g/100ml slurry]	Percent conversion to reducing groups
Arrowroot	2.98 ± 0.030^{d}	15.82 ± 0.162^{e}
Cassava	2.95 ± 0.033^{d}	15.50 ± 0.174^{d}
Curcuma sp.	2.90 ± 0.024^{c}	15.73 ± 0.128^{de}
Dioscorea sp.	2.80 ± 0.031^{b}	15.06 ± 0.168^{c}
Sweet potato	2.81 ± 0.029^{b}	14.80 ± 0.150^{b}
Xanthosoma sp.	2.77 ± 0.030^{b}	14.58 ± 0.157^{b}
Corn (control)	2.66 ± 0.030^{a}	14.30 ± 0.162^{a}
LSD (5%)	0.04353	0.2322

$p < 0.001$; Mean ± SD from four replicates; Means with the same superscript do not differ significantly.

Among different tuber starches, cassava starch was reported to have the lowest gelatinsation temperatures, ranging from 49-64°C[35] to 66-73°C[36]. Gelatinization temperatures of *Xanthosoma*, arrowroot and cassava starches were reported as 85-95°C and 74-87°C, 79-92°C and 68-85°C, 73-90°C and 62-84°C respectively[37,38], while those of *Dioscorea, Curcuma*, and sweet potato fell in the range of 75.92-85.68°C, 74.3-82.1°C and 64.6-84.6°C respectively[39]. The difference in the gelatinization temperatures among the various tuber starches has been attributed to the variation in the starch intermolecular bonds and high gelatinization temperature indicated the higher stability of the starch crystallites in the starch molecules[26].

Cassava starch was found to be easily hydrolyzable by starch degrading enzymes[28,36]. Sweet potato starch was reported to be more resistant than cassava starch to degradation by α-amylase and glucoamylase[40-42] compared digestibility of raw starch of eight sweet potato varieties and found that no significant correlation existed between digestibility and amylose content. The increase in digestibility on cooking could be attributed to the change in starch structure on gelatinization[43] and liquefaction by thermostable amylases like Liquezyme facilitates simultaneous cooking and hydrolysis.

Saccharification of starches: Starches extracted from different sources showed different susceptibility towards enzymatic hydrolysis by the saccharifying enzyme, Dextrozyme. The percentage conversion to reducing sugars and glucose was computed as per the formula given in equation (1) and it ranged from 94.21% to 97.08% and 91.74 to 94.34% respectively for the various tuber starches. This was higher than the conversion value obtained with corn starch (94.09% and 91.80%). Table 3 shows that maximum amount of reducing sugar was obtained in the saccharification of arrowroot (18.27g) and cassava starch

(18.24g) while in the case of corn it was only 17.52g. Saccharification of sweet potato starch slurry also yields a higher reducing sugar content of 18.14g. The reducing sugar contents of *Curcuma* (17.75g), *Dioscorea* (17.81g) and *Xanthosoma* (18.02g) starch slurries were lower than the other tuber starches. The percentage conversion to reducing sugars was maximum (97.08%) after 48h saccharification of liquefied arrowroot starch slurry, while in the case of the other starches, approximately 94-96% (w/w) conversion of starch was achieved. The yield of reducing sugar and glucose will also depend on the absolute starch content of the initial starch material of these starches. In the case of *Curcuma* starch even though the yield of reducing sugar and glucose was only 17.75g and 17.15g respectively, the percentage conversion to reducing sugar and glucose on absolute starch basis was 96.28 and 93.05% respectively. High DE (Dextrose Equivalent) values of 98 after 72h saccharification of wheat starch by multienzyme systems containing α- amylase, gluco-amylase and lysophospholipase was reported by Nebesny et al.[44].

Table-3
Reducing sugar content in the saccharified slurry and percent conversion to reducing sugars

Source of starch	Amount of reducing sugar formed [g/100ml slurry]	Percent conversion to reducing sugars
Arrowroot	18.27± 0.077^{c}	97.08±0.41^{c}
Cassava	18.24± 0.085^{c}	95.95±0.45^{b}
Curcuma sp.	17.75± 0.075^{b}	96.28±0.41^{bc}
Dioscorea sp.	17.81± 0.165^{b}	95.93±0.89^{b}
Sweet potato	18.14± 0.124^{c}	95.70±0.65^{b}
Xanthosoma sp.	18.02± 0.159^{b}	94.79±0.84^{a}
Corn	17.52± 0.075^{a}	94.09±0.40^{a}
LSD (5%)	0.1689	0.900

$p < 0.001$; Mean ± SD from four replicates; Means with the same superscripts do not differ significantly

Glucose formed after saccharification was higher for cassava (17.79g), arrowroot (17.76g) and sweet potato starch (17.70g) as compared to corn starch. The lower values of glucose compared to the reducing sugar values presented in table 3 indicate that the rest of reducing sugars is made up of sugars like maltose or maltooligosaccharides. Maximum percentage conversion of starch to glucose on absolute starch basis was obtained in the saccharification of arrowroot starch slurry (94.34% w/w). In the case of other tuber starches, the percentage conversion to glucose was almost similar (*Ca.* 93%) except *Xanthosoma* starch, in which case the percentage conversion to glucose after saccharification was only 91.74%. Among the tuber starches used for study, *Xanthosoma* starch had the highest absolute starch content (95.07%) which has led to the increased yield of glucose (17.44g/100ml) even though the percentage conversion to glucose on absolute starch basis was lower than other starches (table 1). Chen and Chan[45] reported that cassava starch (96%) and corn starch (93.7%) gave higher glucose yields than rice flour (81.4 to 84%), probably because of differences in the properties of various starches and the Maillard reaction between reducing sugar and soluble protein in the rice slurry. According to Nebesny et al.[46] the application of the mixture of glucoamylase and lipolytic enzymes for saccharification of corn starch could give enhanced concentrations of reducing sugars, as compared to that achieved by digestion exclusively with the glucoamylase. The presence of amylose – lipid complexes interferes with production of glucose syrups because it reduces water binding and swelling of starch granules, thus impairing the access of amylolytic enzymes. However, most of the tuber starches are almost free of lipid complexation unlike in the case of cereal starches and hence the high conversion to glucose achieved in our study with amylase and amyloglucosidase only is justified. The lipid content in starch in different cultivars of cassava varied from 0.11 to 0.22%, while normal corn starch contains approximately 0.87% of lipids, while lipids content in a waxy corn starch is 0.15%, and in a high–amylose starch it reaches 1%[47,48].

Table-4
Glucose content in the saccharified slurry and percent conversion to glucose

Source of starch	Amount of glucose formed [g/100ml slurry]	Percent conversion to glucose/glucose yield[a] [% w/w]
Arrowroot	17.76± 0.057^{c}	94.34±0.31^{c}
Cassava	17.79± 0.057^{c}	93.56±0.30^{bc}
Curcuma sp.	17.15± 0.120^{a}	93.05±0.65^{b}
Dioscorea sp	17.38± 0.128^{b}	93.64±0.69b^{c}
Sweet potato	17.70± 0.072^{c}	93.39±0.38^{b}
Xanthosoma sp	17.44± 0.128^{b}	91.74±0.67^{a}
Corn	17.09± 0.098^{a}	91.80±0.52^{a}
LSD (5%)	0.1455	0.7772

$p < 0.001$; Mean ± SD from four replicates; Means with the same superscript do not differ significantly; [a] Based on absolute starch content of each starch sample used for study

HPLC Analysis of starch-based glucose syrups: Saccharification of starch involves the hydrolysis of oligosaccharides or dextrins produced after liquefaction to low-molecular weight sugars such as glucose, maltose, or a mixture of these and their by-products[49]. Saccharide analysis of the glucose syrups obtained after enzymatic hydrolysis of starches was accomplished with HPLC, in order to identify the major sugars in each hydrolyzate. Table 5 shows the composition of carbohydrates in various starch hydrolysates after 48 h saccharification. It was found that glucose contents in the saccharified syrups of arrowroot, cassava and *Curcuma* were 98.84%, 98.28% and 98.74% respectively based on total carbohydrates analyzed. Maltose content and maltotriose content in the saccharified syrups of the above starches ranged from 1.03-1.69% and 0.03-0.10% respectively. In the saccharified syrup of *Xanthosoma* starch, the glucose content was only 94.76%, while in other starches it ranges from 96.44 to

97.28%. Khalid and Markakis[50] reported that the saccharified syrup of cassava starch consists of 97.6% glucose and 2.4% maltose and higher oligosaccharides on dry matter basis.

Table-5
Carbohydrate profile of the saccharified syrup of various tuber starches

Starch	Composition of starch hydrolysates [%][a]		
	Glucose	Maltose	Maltotriose
Arrowroot	98.84	1.03	0.05
Cassava	98.28	1.69	0.03
Curcuma sp.	98.74	1.16	0.10
Dioscorea sp.	97.28	2.00	0.49
Sweet potato	97.07	2.25	0.53
Xanthosoma sp.	94.76	4.30	0.78
Corn	96.44	3.34	0.22

[a]Based on total carbohydrates analyzed

The results obtained in the present study indicated that the composition of starch hydrolysates obtained for corn was not significantly different from those obtained for each of the tuber starch samples. Therefore, each of these samples was equivalent to corn as a raw material for glucose syrup production under these experimental conditions. The quantity of oligosaccharides should be minimized to ensure high yield and quality of glucose syrup. The major di- and oligosaccharides found in these glucose syrups were maltose and maltotriose respectively. Other oligosaccharides, DP4 (DP = degree of glucose polymerization; i.e. DP-4 = tetraose) to DP-7 were present in low concentrations. Prolonged saccharification resulted in maltose synthesis via transglycosylation which is reported to offset maltose hydrolysis[51,52]. *Xanthosoma* and corn glucose syrup had slightly higher maltose contents than other tuber starches. Lowest maltose content was seen in the arrowroot starch-based glucose syrup i.e., 1.03%. Maltose contents in the glucose syrup of cassava and *Curcuma* starch were 1.69 and 1.16% respectively. In the glucose syrup of other starches, it ranged from 2.0-4.3%, with the highest percentage in *Xanthosoma* starch. Maltotriose was present in low concentrations compared to the other two sugars *viz.,* glucose and maltose and it ranged from 0.03% - 0.78%. Arrowroot, cassava and *Curcuma* seem to be superior to other starches as the carbohydrate composition of glucose syrup of these starches had a higher percentage of glucose content and lower oligosaccharide content than the other starches.

Lower glucose content or higher oligosaccharide content obtained in certain starches suggests the need for an extra dose of glucoamylase or an increase in the reaction time to reach 97-98% glucose content. The optimum saccharification time reported by Fullbrook[53] and Reeve[54] for industrial glucose syrup production from corn was 48-72 h. Nebesny et al[44] reported that larger was the dose of enzyme and the longer was the duration of the reaction, high DE value and better filtration rate was obtained for wheat starch.

Isomerisation of glucose in the saccharified syrup of starches: Approximately, 43- 44% conversion of glucose was obtained from the starch-based glucose syrups (table 6). The highest amount of fructose was obtained in the isomerised syrup of arrowroot starch (17.40g/100ml) with a percentage conversion of 44.09%. Isomerised syrups, from other starches had fructose content in the range of 16.27- 17.22 g/100ml. Degree of isomerisation of glucose to fructose remained the same in all starch based syrups (43-44%), indicating that no significant differences existed among the starches.

Table-6
Fructose content in the isomerised syrups and percent conversion of glucose to fructose

Starch	Initial glucose content [g/100ml]	Amount of fructose formed [g/100ml]	Percent conversion to fructose[a]
Arrowroot	39.46±0.13	17.40±017^{c}	44.09±0.43^{cd}
Cassava	39.53±0.13	17.22±0.17^{c}	43.57±0.43^{bc}
Curcuma sp.	38.11±0.27	16.84±0.16^{b}	44.19±0.44^{d}
Dioscorea sp.	38.62±0.28	16.73±0.17^{b}	43.30±0.43^{ab}
Sweet potato	39.33±0.16	17.20±0.14^{c}	43.79±0.36^{bcd}
Xanthosoma sp.	38.75±0.28	16.64±0.10^{b}	43.06±0.26^{a}
Corn	37.97±0.22	16.27±0.12^{a}	43.02±0.32^{a}
LSD (5%)	0.3233	0.2228	0.5733

$p < 0.001$; Mean ± SD from four replicates; Means with the same superscript do not differ significantly: [a]Based on initial glucose content in starch-based glucose syrup

Aschengreen et al.[11] reported similar results from cassava, potato or corn starches for the production of high fructose syrup. Chen and Chan[45] reported a composition of 50% glucose, 42% fructose and 3% maltose in the high fructose syrup obtained from rice flour. We found that the percentage conversion of glucose to fructose was not influenced by the absolute starch content or glucose content in the saccharified mash, although the fructose yield was proportionate to the glucose content in the mash (figure 1). Figure 1 Studies on the Production of HFS from cassava fibrous residue in our laboratory indicated that the yield of glucose and fructose depended on the starch content in the initial raw material[55]. Dziedzic[56] reported that the percentage isomerization was not directly proportional to the Dextrose Equivalent (D.E) of the glucose syrup.

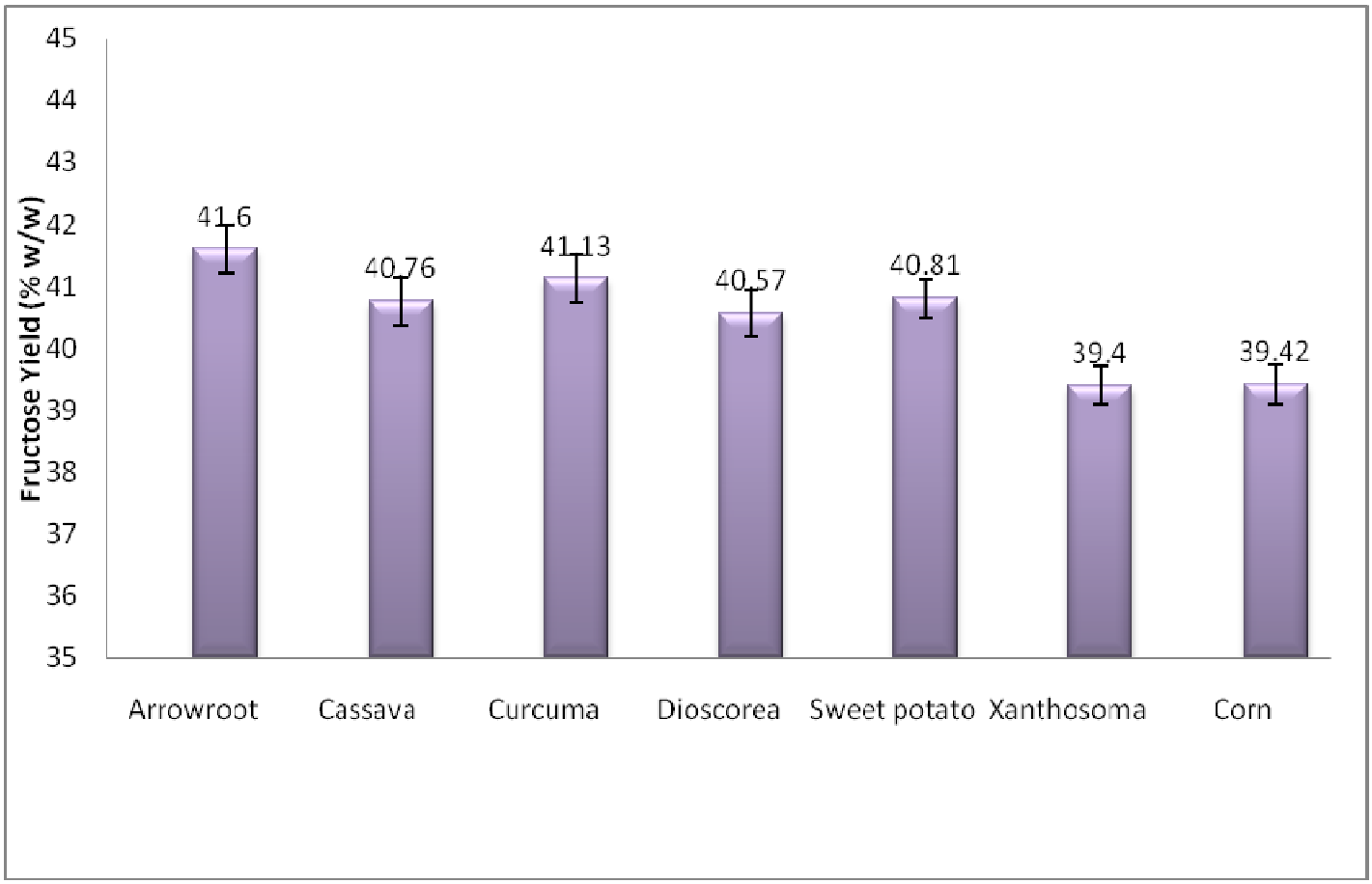

Figure-1
Comparative yield of fructose from various tuber starches *vis-à-vis* corn Starch

Conclusion

The study showed that the fructose yield and percent conversion to fructose from arrowroot, cassava, *Curcuma, Dioscorea* and sweet potato were superior to corn and *Xanthosoma* and hence the five tuber starches could be considered as potential feedstocks for glucose and HFS production. However, the economics of the production depends on the cost of the various starches, the ease of extraction of starch from various tubers, their relative ease of hydrolysis by saccharifying enzymes etc. which could be investigated further. The poor extractability of starch from sweet potato and *Xanthosoma* indicates further scope for research in this direction to place them equally competitive with cassava. Direct conversion techniques from wet tuber slurry or flour based slurry could be developed to economise the whole process.

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