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Biochemical changes in greater yam (*Dioscorea alata*) tubers at different stages of maturity

Tuber crops especially yams are important energy sources in the diet in many parts of Africa and Asia. Yam's potential as a source of food is attributed to its high levels of carbohydrates including fibre, starch and sugar, contributing about 200 dietary calories per person per day to 300 million people in the tropics (Mignouna et al. 2008). Yam is cultivated considerably to withstand the food threats of the rising population in the world (Asiedu and Sartie, 2010). It also provides other nutritional benefits such as proteins, lipids, vitamins and minerals. The *Dioscorea* species that is most widely distributed across the tropics is *Dioscorea alata*, which was acquired from Asia and Africa in the sixteenth century. *Dioscorea alata* has high fibre content and low glycemic index (Ampofo et al. 2020). Even though yams are highly nutritious and have a lot of potential for usage, they only provide a modest quantity of protein (0.32 to 2%). Up to 19-20% of the starch in greater yams is made up of amylose and amylopectin. Furthermore, yams include additional beneficial bioactive compounds such flavonoids, saponins, and phenolic compounds, making them an excellent choice for daily consumption (Lebot et al. 2023).

Greater yam is grown in the Indian states of Andhra Pradesh, Uttar Pradesh, Bihar, Kerala, Maharashtra, Odisha, West Bengal and the north-eastern states. Yam tubers are spherical, cylindrical oval, or flattened, and are typically formed underground. The flesh of the tubers can vary in colour from off-white to dark brown, while the skin can be any shade of yellow, purple, pink, or yellow depending on the type. Yam tubers have a significant nutritional value; they include roughly 75.6 to 83.3% carbohydrates, 3 to 7.4% protein, 0.5 to 1.5% fiber, 0.7 to 2.0% ash, 0.02 to 0.5% fat and 13.0 to 24.7 mg of vitamin C per 100 g (Wanasundera and Ravindran, 1994; Opara, 1999).

The cultivars of greater yam is highly heterozygous. Each variety will have its own biochemical and nutritional attributes. In a study carried out in Sri Lanka, moisture and total carbohydrate contents of selected yams ranged from 62.61 to 73.15% and 18.30 to 26.84%, respectively. The crude fat content ranged from 0.06 to 0.18% in the tested yams. Crude protein levels ranged from 1.30 to 1.91%. The ash content varied between 0.64 and 0.84%. K, Mg, Na, Zn and Fe were the most abundant mineral elements in tested yams where potassium showed the highest availability (4.61 to 5.12 mg g^{-1}). Significant differences of crude fat, crude protein, ash and most of the mineral contents were observed among different accessions of the same species (Kulasinghe, 2018). It is assumed that the nutritional composition may vary with stages of maturity of tubers. Therefore, the present study was conducted to assess the biochemical and nutritional composition of greater yam tubers harvested at different stages of maturity.

The tuber samples were collected from the greater yam crop planted at different planting densities and harvested at different stages of maturity at ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India. Greater yam variety Sree Nidhi, released by ICAR-CTCRI for Kerala state was used for the study. Tubers are cylindrical with light pink cortex and white flesh colour and good culinary quality. The crop was planted at seven different planting densities (S1: 120 × 60 cm; S2: 90 × 90 cm; S3: 90 × 75 cm; S4: 90 × 60 cm; S5: 75 × 75 cm; S6: 75 × 60 cm; S7: 60 × 60 cm) with three replications. All the cultivation practices were imposed uniformly following the package of practices recommended by ICAR-Central Tuber Crops Research Institute (CTCRI). The tubers were harvested at different stages of maturity *viz.*, 2 months prior to maturity (M1), one month prior to maturity (M2) and at full maturity of the crop (M3) across all the planting densities, *i.e.*, 7, 8 and 9 months after planting.

The harvested tubers were collected from each plot and cleaned and replicated samples were used for analysing dry matter, starch, sugar, crude protein content and crude fibre content as per standard procedures (AOAC, 1995). Pooled samples from both ends and middle portion of tubers were used for biochemical analysis representing the whole tuber. The data were subjected to statistical analysis and Analysis of Variance (ANOVA) was

performed using the GRAPES (2020). Statistical analysis of the data on different biochemical attributes of greater yam tubers indicated no significant difference between different planting densities, when harvested at a time. However the data differed statistically when analysed at various stages of maturity and harvesting.

Dry matter content

The dry matter content of tubers is found to increase with maturity. Dry matter content increased with a significant difference between sampling at different stages of maturity. The highest value was observed for M3, at full maturity (29.3%). The values ranged from 23.5 to 29.3% at various stages, clearly depicting the reduction of tuber moisture content when tubers attain maturity. The dry matter content of tubers collected at each stage of maturity from multiple planting densities did not significantly differ from one another. But a general increase was observed when harvesting was delayed. At two months prior to maturity, highest dry matter (27%) was for S2 (90 × 90 cm spacing) and the lowest for S5 (75 × 75 cm spacing) (20.8%). The dry matter increased when tubers were harvested at one month prior to maturity and the values reached 24.6% (S3) to 28.8% (S1). The highest dry matter content of 31.6% was recorded by S7 at full maturity, though the values were at par between planting densities. Dry matter content of different varieties differ, recording higher values towards maturity, showing an inverse relationship with tuber moisture content (Treche and Agbor, 1996). In Sree Karthika, another improved variety of greater yam, dry matter is reported as 37.06% followed by 36.07% in local variety in Chhattisgarh (Padmakshi Thakur et al. 2023).

Starch content

There was an increasing trend in starch content of tubers with increase in maturity. The highest starch content was recorded at full maturity, and the values were 13.6, 18.3 and 20.2% respectively at 2 months and one month prior to maturity and at full maturity and the values did not differ significantly at first two stages of harvest. There was no definite trend observed due to planting densities when harvested at various stages. The highest starch content was observed with S4 (15.4%) at 2 months, S5 at one month before maturity (20%) and S3 at full maturity (22.8%). As the tubers reach maturity, the starch content increased without changing appreciably (Table 1). Yam is classified as an energy food source to consumers especially in Sub-Saharan Africa because of its high starch content. Among the *Dioscorea* spp., *D. alata* has been reported to contain a relatively high starch content when compared to other species. Greater yam is the best source of starch, having a higher calorific value and a higher protein content than cassava and sweet potato (Afoakwa et al. 2013). The starch content of *D. alata* depends on several environmental factors, agronomic practices as well as degree of maturity. Active tuber development in greater yam varieties *viz*., Sree Keerthi and Sree Karthika by way starch deposition was noticed from 4 to 8 months after planting (Sunitha et al. 2020).

Sugar content

In contrast to the starch content, sugar content of greater yam tubers showed a decreasing trend with maturity (Fig.1). The values varied from 1 to 1.7% at 2 months prior to maturity, 0.6 to 1.2% at one month prior to maturity and 0.6 to 0.9% at full maturity with varying planting densities, but were more or less the same statistically. Planting density did not cause any variation in sugar content of tubers at any stages of harvesting (Table 1).

Total soluble sugar content is an important trait and low sweetness is often favoured in yam. The sugar content can vary among different yam species and even within the same species due to a variation in variety, growing conditions and processing methods. Lebot et al. (2019) reported that the sugar mean values were highly variable within species and ranged from 0.16% in *D. dumetorum* to 3.15% in *D. esculenta.* In the present study the values ranged from 0.6 to 1.7% when harvested at different stages in *D. alata.* In another study, the sugar content ranged from 2.43% to 6.91% while the reference variety had a value of 4.60% (Aprianita., et al., 2009). Baah et al. (2009) reported a sugar content of 5.40% in *D. alata* from Nigeria. An inverse relationship is observed between starch and sugar content in most of the tuber crops and a higher starch is preferred for yams towards maturity as a food security crop.

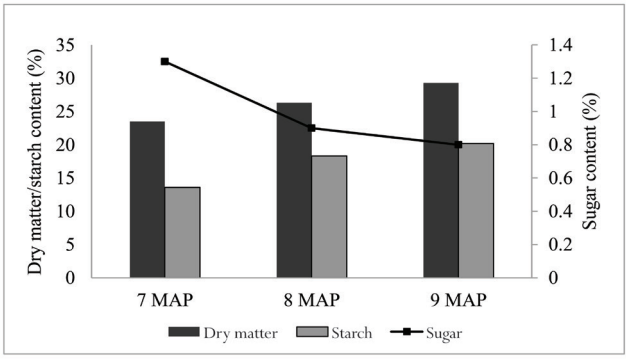

Fig.1. Changes in dry matter, starch and sugar content in yam tuber at different stages of maturity

Crude Fibre content

There was no significant variation in crude fibre content of tubers either with stages of maturity or planting densities. But a decreasing trend was observed in fibre content with maturity. The fibre content varied from 0.7% (at full maturity, 75 × 60 cm spacing) to 2.0% (wider spacing of 120 × 90 and 90 × 90 am at 2

Table 1. Starch, sugar and protein content of greater yam tubers at different planting density and stages of maturity

Planting density	Starch (%)			Sugar (%)			Crude protein (%)		
	7th month	8th month	9th month	7th month	8th month	9th month	7th month	8th month	9th month
S1	11.8	15.0	15.0	1.3	0.9	0.8	2.2	2.8	2.7
S2	13.7	19.6	20.7	1.5	0.8	0.6	2.7	2.6	2.9
S3	14.8	19.1	22.8	1.3	1.2	0.9	2.0	2.2	2.0
S4	15.4	16.7	21.9	1.0	0.6	0.7	2.6	2.9	2.9
S5	13.7	20.0	19.7	1.2	0.8	0.7	2.6	2.4	2.1
S6	12.1	16.3	20.1	1.7	0.8	0.7	2.6	2.5	3.0
S7	13.5	21.4	21.2	1.2	0.9	0.8	2.3	2.1	3.0

months prior to maturity). The higher planting density also showed more fiber content, but the effect was not significant. The greater yam contains dietary fibre, which plays a vital role in the digestive system of humans as well as animals (Dhingra et al. 2012). Fibre content of yams is mostly attributed as varietal character. Behera et al. (2009) reported that the crude fibre content of the tuber was in a range of 1.39 to 2.60% in the first year of the study while, it was 1.46 to 2.53% in the second year. Invariably, fibre content showed a declining trend with maturity, mainly because of the deposition of more starch in tubers towards maturity.

Crude Protein content

Crude protein content increased with maturity of tubers and highest value was observed at full maturity. Significant variation in crude protein content was not observed in samples before maturity, but an increase was noted when sampling was delayed. The values ranged from 2 to 2.7% at 2 months prior to maturity, 2.1 to 2.9% at one month prior to maturity and 2 to 3% at full maturity, though the values were not significantly different between planting densities. Increasing planting density also resulted in more protein content compared to lower planting density (Table 1). At full maturity, planting densities of 75 × 60cm and 60 × 60 cm spacing recorded the highest protein content of 3.0%. Planting density can impact nutritional quality by influencing how plants compete for resources and how well individual plants grow. Present study was conducted in a medium fertile soil, adequately supplemented with nutrients. Hence a significant variation in nutritional attributes was not observed between planting densities, but only with maturity of tubers.

Studies revealed that the starch content of different cultivars of greater yam ranged from 17.3% to 29% and the protein content about 1.6% to 2.5% (Wanasundera and Ravindran,1994). Yams appear to contain enough protein to merit nutritional considerations. The greater yam cultivars present significant variation in protein content (4.1-20% d.w.). Yams (*Dioscorea* spp.) contained 6.3 to 13.4% crude protein, as measured by the Kjeldahl N technique. Very high protein contents are found (15-20%) but they usually correspond to poor quality cultivars (Lebot and Malapa, 2013). Protein content varies with different portions of tubers and the peel rich in protein is a minor part of the tuber weight. In the present study, the protein was estimated taking composite sample of the tuber and was measured by Kjeldahl's nitrogen technique. In a study to assess the chemical and nutritional attributes of great yam varieties, dry matter content ranged from 22.3 to 33.8% on a fresh weight basis with corresponding moisture content between 66.2 and 77.7%. The ranges of crude protein, ash, sugar, starch and total dietary fibre were 4.3-8.7, 2.9-4.1, 3.6-11.0, 60.3-74.4 and 4.1-11.0%, on dry weight basis, respectively (Baah et al. 2009).

As observed in earlier studies, active tuber development in greater yam is from 4 to 8 months after planting. In the present study also, tuber development must have been during this stage and tuber maturity, after 8 months of planting. As the tubers mature, it was observed to contain more starch and protein, less sugar and fibre content. The study highlights the importance of right stage of harvesting of tubers, ie, at full physiological maturity, which is indicated by senescence and drying of vines, to ensure food and nutritional attributes.

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