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Optimizing the harvesting time of Palmyrah (*Borassus flabellifer*) haustorium to retain its nutrient content without affecting the development of tuber

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ABSTRACT

Palmyrah haustorium, consisting of nutritional values for mankind is generally wasted without consumption. The main aim of this research is to find the best developmental state of Palmyrah haustorium at which more nutrients are retained for the betterment of human health while taking care not to disturb the traditional tuber production. Raised seed beds were made with randomly selected 400 similar seeds (age, size, variety) in four different places in Jaffna peninsula, Sri Lanka. Those four places were Island, Thenmaradchi, Vadamaradchi and Valikamam. Samples consisting of 40 seeds were collected in three week time intervals, starting from sixth week of germination. The haustorium was analyzed for change of mass and amounts of nutrients while starch and total sugar present in tuber were also analyzed. Mass of haustorium in samples of Island and Valikamam increased steadily up to 9th week with values 19.25 and 21.17 g/seed respectively whereas samples of Thenmaradchi and Vadamaradchi showed their maximum having 16.64 and 15.76 g/seed respectively. Sugar content of haustorium was found to be at their maximum at the age of 12 weeks and afterwards their concentrations started to decline. Total phenolic content had almost reached the maximum and an appreciable amount of protein was found in all the four different samples at the end of 12th week. On the other hand a drop in starch content and an increase in sugar content were observed in tubers at this stage. Taking into account the nutritional content of both haustorium and the tuber, it was concluded that harvesting should be done at the end of 12th week.

Keywords: Palmyrah, Haustorium, Tuber, Nutritional changes, Locations

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INTRODUCTION

Today, consumers' perception towards the high quality, healthy foods which provide additional health benefits beyond the basic nutritional requirements is becoming greater than ever. With increased awareness of a healthy lifestyle based on consumption of functional foods or other functional ingredients, natural foods have gained greater popularity over artificial foods and this makes scientists to search for plant resources to fulfill the requirements of the consumers.

Palmyrah palm (*Borrasusflabellifer*) belongs to the family palmae, grows well in the arid zone. The female palms produce fruits and on maturation the ripened fruits automatically fall to the ground. Few fruits along with seeds are collected by people to extract the pasty mesocarp and mix with water to produce a diluted pulp in order to get a sun-dried flat sheet, called 'Pinnattu'. The remaining fruits are heaped up for a short period and then beds are made with three or four tiers of seeds and their moisture level is maintained adequately to form tubers.

As a general practice, Palmyrah (*Borassusflabellifer*) tubers are harvested at their full maturity stage and the remainder of the seed bed after harvesting is thrown to nature though it has benefits for humans.The residuum of the seed bed contains Palmyrahhaustorium which is a delicious white, spongy edible part formed during germination. On germination, the basal part of the embryo enlarges to form the cotyledony structure, and this is called haustorium. The haustorium transfers the nutrients to the embryo. Hence haustorium will be more nutritious containing sugars, essential amino acids and other micro nutrients and bio active compounds which are highly beneficial for our health. People in rural areas consume it raw and fresh. It has been proved through scientific

investigations that an increased consumption of this haustorium has several health promoting as well as disease preventing benefits [1]. Haustorium actually transfers the nutrients to tubers which ultimately produce valuable plants. Therefore, in order to get more healthy plants and nutritious tubers the harvesting must be properly practiced. Proper harvesting period has to be clearly identified to minimize the wastage of nutritious resources.

However, the haustorium now harvested at the final stage after digging up the tubers is watery and has no taste whereas the tubers develop sugars and the starch content get reduced resulting in poor quality of tubers for further processing. Therefore analyzing the haustorium for its nutrients and palatability is very helpful in determining the proper harvesting time at which deliciousness and nutrients are retained at optimal level for both haustorium and tubers of Palmyrah, without affecting the development of the tuber. Analysis of the tuber for its important nutrients at different maturity levels will also help to avoid the damage and wastage of these resources.

In this research study, it has been hypothesized that the nutrient composition and organoleptic properties of haustorium vary with its developing (ripping) time and that proper harvesting period may prevent wastage of resources and loss of nutrients. The study in this paper illustrates an effort to determine the proper harvesting period for haustorium containing the highest possible nutrient content. This could pave way to increase the utilization of an under-utilized resource existing abundantly in Sri Lanka.

MATERIALS AND METHODS

Selection of study site

In order to analyze the parameters of Palmyrah haustorium in Jaffna peninsula the district was divided into four divisions such as Island, Thenmaradchi, Vadamaradchi, and Valikamam according to the different soil types as shown in Figure 1.

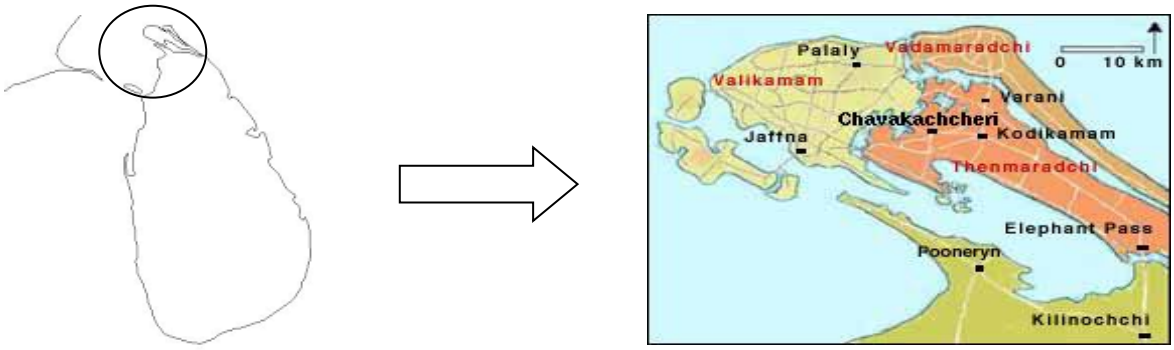

Figure 1: Site map (google map).

Preparation of seed bed for Palmyrah haustorium and tuber development

Same age and variety of 400 medium sized seeds were collected randomly from study sites during October 2015.

Sampling technique

At the time interval of three weeks, seeds were harvested by systematic sampling from all four corners and center of seed bed. According to statistical theorems, at least 10 % of the total population of the seed bed had to be sampled and therefore 40 seeds with 40 tubers were harvested at each interval.

Preparation of samples

Harvested haustorium was mixed well and then the sample size was reduced using quartering method. Samples were dried at 80^0C for overnight, ground, homogenized and then packed in air tight containers. The sample bottles were kept at room temperature condition.

Proximate composition

Association of Official Analytical Chemists (AOAC) methods were used to determine the Moisture [4], crude fat [5], protein [5], dietary fiber [4], starch [2], and total ash [4].The protein content of the samples was calculated using the factor N×6.25. Sugar content was determined by use of an UV visible spectrophotometer (Thermo Scientific GENESYS 10S UV/Vis, USA)[8].

Mineral content

Potassium and sodium content was estimated using aflame photometer [5]. Calcium and magnesium were determined by EDTA titrametric method [7]. Determination of iron was carried out by a spectrophotometric method using 1, 10- phenanthroline [7].

Total phenolic content of haustorium

The total phenolic content of Palmyrah haustorium was determined by Folin-Ciocalteu method [6].

Antioxidant activity using DPPH method

Ascorbic acid was used as the reference standard,to quantify the free radical scavenging capacity, , which was expressed as ascorbic acid equivalent [3].The inhibition percentage was calculated using the absorbance readings. Finally IC_{50} value of the standard was calculated.

Samples were analyzed in triplicate and the results reported are the mean values ± standard deviation (SD).

RESULTS AND DISCUSSION

The optimal harvesting period was determined by analyzing the haustoruim and tuber harvested at different time intervals.

The study of changes of mass in haustoriumand tuber with the time

The average mass of haustorium (g/100 g) dry matter examined is shown in Table 1.According to the results obtained for Thenmarachi and Vadamaradchi samples, the yield slightly increased up to 12th week and then Thenmaradchi sample increased and the other decreased. However all four samples were almost similar in the 12thweek.Among the four, two samples (Island and Valikamam) showed the highest yield in the 9th week and the rest of the two showed their highest yield in 12thweek (Vadamaradchi) and 15thweek (Thanmaradchi). Hence the decision of determining the harvesting period should be made considering the results from further analysis.

Table 1: Average mass of haustorium with definite harvesting time in different selected areas in Jaffna penninsula.

Place	Average mass of haustorium (g per seed)			
	Fixed intervals (weeks)			
	6th	9th	12th	15th
Island	11.67 ±0.10 ^{d}	19.25±0.51 ^{a}	15.04±0.19 ^{b}	13.30±0.80 ^{c}
Thenmaradchi	12.20±0.17 ^{d}	14.89±0.16 ^{c}	16.64±0.48 ^{b}	17.10±0.29 ^{a}
Vadamaradchi	7.60±0.70 ^{d}	13.00±0.36 ^{b}	15.76±0.45 ^{a}	14.80±0.66 ^{c}
Valikamam	10.07±0.20^{d}	21.17±1.21 ^{a}	15.20±0.38 ^{b}	12.00±0.89 ^{c}

Each value in the table was represented as mean ± SD (n = 3). Values in the same row followed by a different letter (a-d) are significantly different ($p< 0.05$).

Mass of the haustorium indicates the mass of nutrients. During the germination of seed, haustorium increased in mass rapidly up to 9th week; hence all samples showed the increase in mass (Table 1). The difference observed between samples at 12th week of harvesting could be due to variation of internal and external environment of seed samples. It might be assumed that the function of haustorium at this state might be high. After 12th week, mass of haustorium decreased probably because nutrients of it are transferred to the embryo as the function of haustorium isto nourish.At this time mass and length of tubers increased (Table 2). All samples from the four different areas showed similar trend in the yield of tubers. Difference in mass of haustorium among the samples is not significant. Yet sudden decrease in mass was observed after 12th week except for the sample collected from Thenmaradchi. However, the percentage increases in the Mass (yield) with the growth fall between 4%and 6 % indicating that the increase of mass within the growth period as slow (figure 2).

Table 2.Average (mass and length) of tuber against the growth period in different areas.

Place	Average mass of tuber (g per tuber)		Average length of tuber (cm per tuber)	
	Fixed intervals (weeks)		Fixed intervals (weeks)	
	12^{th}	15^{th}	12^{th}	15^{th}
Island	77.34 ±3.81	80.67 ±3.21	34.57 ±1.65	36.17±1.14
Thenmaradchi	52.00±4.00	54.67±4.51	21.90±1.20	22.80±1.60
Vadamaradchi	61.67±2.08	65.34±2.51	27.34±1.96	28.84±2.50
Valikamam	40.34±4.04	42.34±3.79	16.83±1.25	17.67±1.50

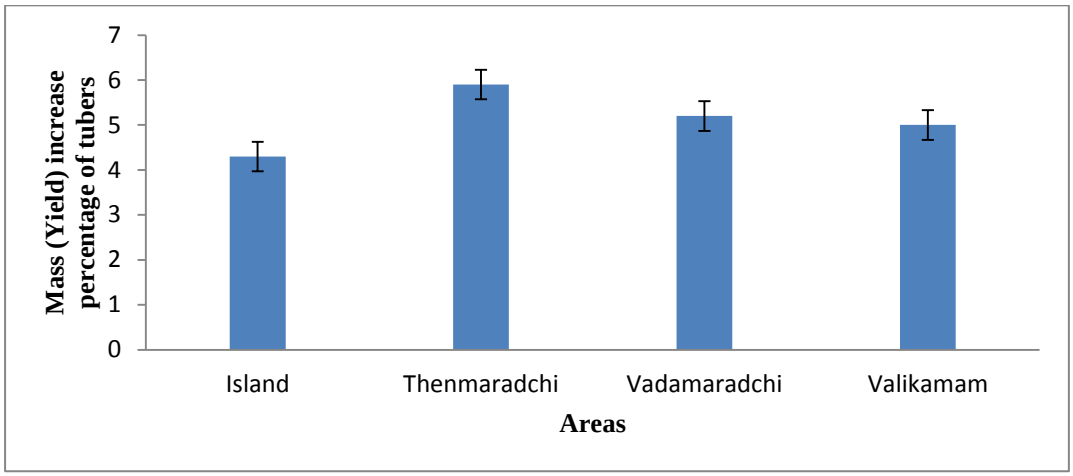

Figure 2: Percentage increase in yield of tubers with time in different areas in Jaffna.

The study of sugar content Haustorium with the time

Total sugars and reducing sugars of Palmyrah haustorium are the most desirable characteristics as people prefer haustorium for its sweetness and health benefits rather than its nutritional value. As shown in table 3 reducing sugar of the haustorium in all four different samples significantly increase up to 12^{th} week and maximum concentration of reducing sugar was detected in all four samples at 12^{th} week. Haustorium from Island showed the highest content while the sample from Thenmaradchi showed the lowest among the four different samples at 12^{th} week. However the trend of increase was similar to all. The increment may be due to the accumulation of sugar in the haustorium increases with age while mass of haustorium's tissue increased. Inevitably, the size of the embryo also increased utilizing the nutrient supplied by the haustorium.

Table 3: Reducing sugars in haustorium harvested at fixed time intervals.

Place	Amount of reducing sugars (g/100g)			
	Fixed time intervals (weeks)			
	6^{th}	9^{th}	12^{th}	15^{th}
Island	14.15 ± 0.52^{d}	19.23 ± 0.24^{c}	40.26 ± 0.57^{a}	31.62 ± 0.15^{b}
Thenmaradchi	9.79 ± 0.10^{d}	25.82 ± 0.07^{b}	32.49 ± 0.05^{a}	17.96 ± 0.08^{c}
Vadamaradchi	5.72 ± 14.79^{d}	14.79 ± 0.70^{c}	32.83 ± 0.76^{a}	30.91 ± 0.47^{b}
Valikamam	12.78 ± 0.01^{d}	22.95 ± 0.34^{c}	34.77 ± 0.92^{a}	25.17 ± 0.31^{b}

Each value in the table is represented as mean ± SD (n = 3). Values in the same row followed by a different letter (a-b) are significantly different ($p< 0.05$).

Total sugar content of haustorium showed a similar trend as reducing sugars. As displayed in table 4, the concentration of total sugars increased with time till 12th week and then decreased and the differences in values between different time points were significant.

Table 4: Total sugars of haustorium harvested at fixed time intervals.

Place	Total sugar content (g/100g) with fixed time intervals			
	6th	9th	12th	15th
Island	66.96±5.92[d]	84.98±0.26[c]	89.52±0.52[a]	73.54±1.01[b]
Thenmaradchi	66.13±2.47[d]	87.82±0.50[b]	89.83±0.64[a]	78.65±0.51[c]
Vadamaradchi	65.02±0.39[d]	79.19±0.26[c]	93.27±1.14[a]	69.82±0.38[b]
Valikamam	78.14±1.16[d]	80.45±0.77[c]	95.90±0.38[a]	68.26±0.25[b]

Each value in the table is represented as mean ± SD (n = 3). Values in the same row followed by a different letter (a-b) are significantly different ($p< 0.05$).

The data from table 3 and 4imply that 12th week is the suitable time for harvesting the haustorium as the decline in sugar level after 12th week will affect the taste of it. Also, it would be a suitable time for harvesting the tubers as well.

The study of starch and sugar content of tubers with the time

The suitable mature stage at which tubers should be harvested for processing mainly depends on the starch content. Hence starch was analyzed at two different ages of the tuber.

Starch of tubers from all four areas decreased with time (Table. 5). Palmyrah tubers from Vadamaradchi showed highest content of starch whereas Valikamam tubers showed the lowest.. Amount of starch in Thenmaradchi tubers did not change drastically while the Island tubers showed a sudden decrease with time. However, tubers must be harvested before the declining of the starch content. Therefore, 12thweek should be the best time to harvest the tubers.

Table 5: Change of amount of starch and sugar in Palmyrah tubers with age.

Place	Starch content (g per 100 g)		Total sugar content of tuber (g/100g) with fixed time intervals	
	Age of tuber (weeks)		Age of tuber (weeks)	
	12th	15th	12th	15th
Island	70.35 ±1.65	62.00±1.14	11.21±0.45	15.85±1.86
Thenmaradchi	60.01±1.20	59.72±1.60	15.51±0.78	18.44±0.42
Vadamaradchi	73.70±1.96	68.78±2.50	11.39±1.47	17.33±0.13
Valikamam	53.95±1.25	50.90±1.50	9.41±0.36	11.66±0.92

According to the results obtained from the analysis of total sugars of tubers, the tubers at the age of 15th week showed the highest total sugar content than the earlier stage which was observed for all four types of samples (Table. 5). The sample of Thenmaradchi showed the highest among all four at both 12th and 15th week of age. Also, the sugar level increased concomitantly as starch content declined. This is because at 15th week starch might have

been hydrolyzed to sugar and then transferred to shoot and root. At this stage new true leaf would grow, therefore utilization of food by the growing plant must be very high.

The study of Total phenolic content in haustoriumwith the time

The total phenolic content of haustorium had a significant change with the growth period as illustrated in table 6. Haustoriums grown in the four different places contain the total phenolic content between 500 mg/100g to 1g/100g, indicating that it has a great antioxidant potential.

Table 6: Total phenolic content in haustorium at fixed time intervals.

Place	Total phenolic content of haustorium with fixed time intervals (weeks) (mg/100g)			
	6th	9th	12th	15th
Island	770.21±2.86^{d}	821.68±14.48^{c}	899.44±2.00^{b}	926.70±12.82^{a}
Thenmaradchi	597.10±107.67^{d}	599.78±8.66^{c}	822.37±1.91^{b}	824.02±3.59^{a}
Vadamaradchi	578.43±8.75^{c}	520.98±11.62^{d}	692.17±11.67^{b}	962.88±2.87^{a}
Valikamam	640.39±21.35^{c}	639.53±6.75^{d}	946.09±42.51^{b}	950.26±11.80^{a}

Each value in the table is represented as mean ± SD (n = 3). Values in the same row followed by a different letter (a-b) are significantly different ($p< 0.05$).

As shown in table 6, total phenolic content increased with harvesting period for all four different places. At 12th week, among the four different samples, haustorium grown in Island and Vadamaradchi showed highest and lowest content respectively. At 6th week and 9th week, phenolic content is not significant because haustorium might have been at an immature stage. Synthesis of phenolic content might have happened later. Table 6reveals that the total phenolic content increased with maturity of haustorium up to 12th or 15th week.

The study of change of the amount of total dietary fibre in haustorium with the time

In contrast to sugars and total phenolic content, a differenttrend was observed in dietary fibre content with the time of growth of haustorium. All four places hit their minimum at 9th week and slightly increased at 12th week. Then the values suddenly increased to their highest at 15th week. It is clearly illustrated in figure 3.

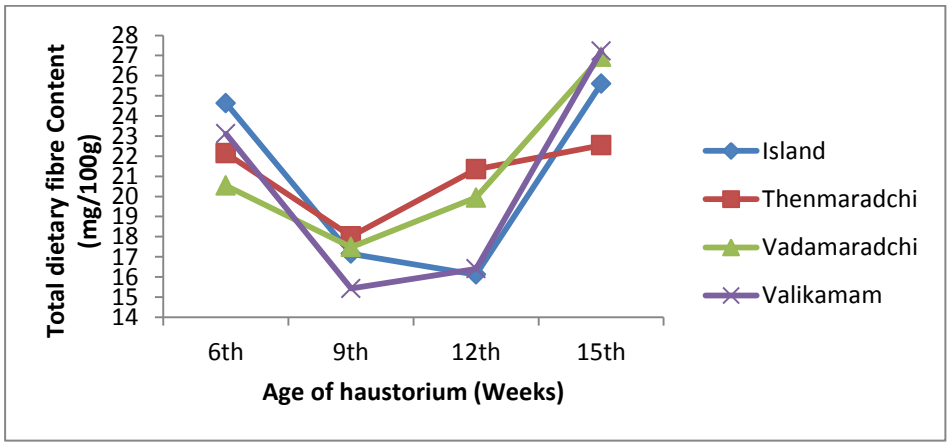

Figure 3: Change of the amount of total dietary fibre in haustorium with time.

Initially, haustorium was small in size. This might be due to the high content of dietary fibre. Then other tissues developed, softened and gave a less fibrous nature to haustorium. Later on it had become more fibrous in nature. This might have been the case due to the declining nutrient transfer.

The study of moisture, protein and fat content in haustorium at 12th week

Moisture content usually decides the taste and palatability of the product. Here the adequate moisture content present in the samples might encourage the consumers to consume the product more and more. The moisture content of Palmyrah haustorium obtained from Vadamaradchi was the lowest and the highest moisture content was shown by haustorium of the Islands as shown in Table 7. However all haustorium samples contained the moisture content value above 80%.

Table 7: Nutritional content of Palmyrah haustorium at 12th week.

Places	Nutritional content (g / 100g)	
	Protein content	Fat content
Island	7.90±0.17	0.14±0.47
Thenmaradchi	7.64±0.32	0.39±0.78
Vadamaradchi	8.02±0.45	0.13±0.24
Valikamam	7.49±0.78	0.36±0.18

If haustorium consists of more protein it will attract the consumers. Table 8 shows that the protein content of the haustorium in the four places lies in the range between 7 to 8 g per 100g, where protein content of Haustorium from Vadamaradchi showed the highest.

According to table 8, the fat content of Palmyrah haustorium from Thenmaradchi and Valikamam showed the highest and almost similar values whereas the other two types of samples showed the lowest values; hence the samples could be categorized into two groups. Also the fat content varied in the samples in comparison with the content of protein. When protein increased the fat in the same sample decreased.

The study of mineral content in haustorium with the time

All four places showed significantly higher mineral content at 6thweek and it significantly reduced at the end of 12th week and it again increased at 15th week. At 12thweek of harvesting, Thenmaradchi had the highest mineral content and Island haustorium showed the lowest mineral content when compared with the other two places. The ash content decreased with the growth period in all four places and at the beginning, Vadamaradchi haustorium contained the highest mineral content which drastically decreased with age. The results are shown in table 8.

Table 8: Total ash content of haustorium of palmyrah.

Place	Ash content (g/100g) of haustorium at fixed time intervals (Weeks)			
	6th	9th	12th	15th
Island	5.83 ±0.86^{a}	5.01 ±0.32^{b}	3.30 ±0.23^{d}	4.94 ±0.04^{c}
Thenmaradchi	5.95 ±0.39^{a}	4.19 ±0.16^{d}	4.28 ±0.02^{c}	4.30 ±0.02^{b}
Vadamaradchi	6.42±0.20^{a}	4.84±0.09^{b}	3.40±0.17^{d}	4.36±0.14^{c}
Valikamam	5.80±0.08^{a}	3.75±0.03^{d}	3.78±0.08^{c}	4.07±0.06^{b}

Each value in the table is represented as mean ± SD (n = 3). Values in the same row followed by a different letter (a-b) are significantly different ($p< 0.05$).

Table 9 indicates that potassium was higher in all samples whilst iron content was negligible when compared to the other minerals considered here. Calcium was the second highest mineral in haustorium. Haustorium of Thenmaradchi contained the highest amount of potassium and sodium whereas haustorium from Vadamradchi

contained the highest amount of calcium. These differences in mineral abundance might affect the composition of haustorium.

Table 9: Mineral content of Palmyrah haustorium.

Place	Mineral (mg/100g)				
	Sodium	**Potassium**	**Calcium**	**Magnesium**	**Iron**
Island	23.88±0.16[a]	48.36±0.11[d]	64±0.23[b]	39±0.66[d]	0.34±0.42[c]
Thenmaradchi	23.86±0.21[a]	99.86±0.51[a]	55±0.17[c]	41.4±0.63[c]	0.19±0.12[d]
Vadamaradchi	20.31±0.06[b]	85.93±0.18[c]	71±0.12[a]	45±0.64[a]	0.45±0.15[a]
Valikamam	15.23±0.07[c]	93.45±0.54[b]	65±0.64[c]	43±0.21[b]	0.41±0.12[b]

Each value in the table is represented as mean ± SD (n = 3). Values in the same column followed by a different letter (a-b) are significantly different ($p < 0.05$).

The study of phenolic content of in Palmyrah haustorium in different areas

Antioxidant activity is due to the phenolic components present in the haustorium. The extraction of antioxidant is the most important factor in their determination. Yet, based on the study by Arunachalam et al (2012) [1] acetone was selected as the best solvent for phenolic compound extraction from haustorium.

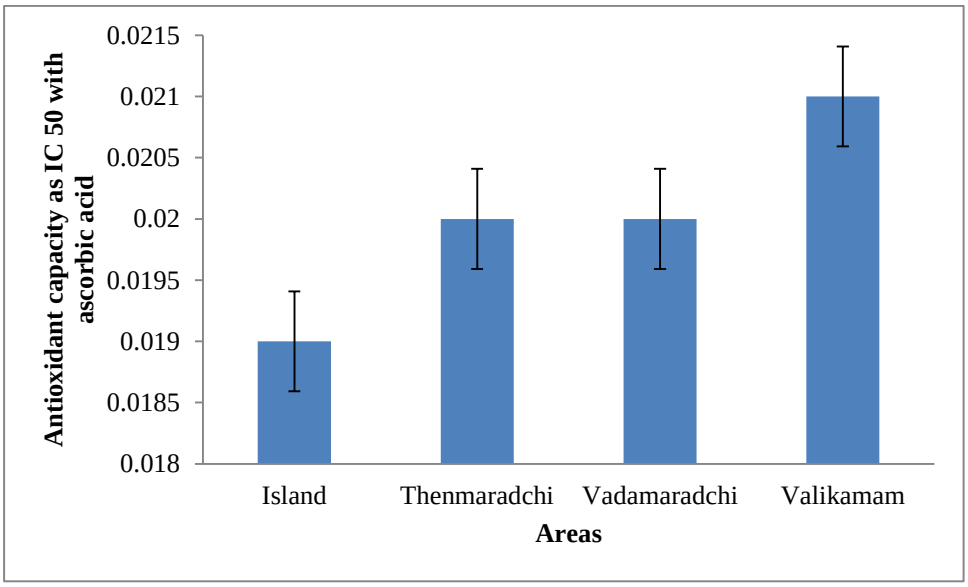

Figure 4: Antioxidant activity of Palmyrah haustorium in four different areas in Jaffna.

As shown in figure 4, Palmyrah haustorium from Valikamam contained the highest antioxidant activity whereas the haustorium from Island had the least among the four different samples. The other two types of samples had almost similar antioxidant activity to each other. However all four had significant amount of antioxidant capacity in terms of ascorbic acid.

Presence of antioxidant activity in the haustorium is beneficial to the health of the consumers. Mainly it saves humans from cancer. Since all four different samples (places) showed the presence of the antioxidant activity, haustorium consumption gives health advantages to humans.

According to the results obtained from the analyzed parameters, the values were at their maximum at 12th week of haustorium's growth, except for the dietary fibre which was at its lowest value at 12th week. In the case of Palmyrah tubers, starch was at its maximum at 12th week and then declined whereas the total sugar showed the opposite trend. This is because of the biochemical changes that occur during the growth of a plant.

When a Palmyrah seed germinates embryo forms two parts namely haustorium and cotyledon. Cotyledon turns to radicle and then forms a new plant while haustorium absorbs the nutrients from endosperm and transfers them to cotyledon. After haustorium penetrates into endosperm it sucks up the nutrients and converts the complex nutrient molecules into their simple forms such as simple sugars, amino acids etc for its growth which would take few weeks,. At this stage the abundance of sugar and other essential nutrients, phytochemicals etc of haustorium will be higher. However the growth of cotyledon occurs after 6 weeks when it starts to get nutrients from the haustorium. At 12^{th} week the tuber is formed and it starts growing as a new plant. Therefore tubers start absorbing the nutrients in haustorium. This absorption of nutrients into the tubers reduces reducing sugar and total sugars in the haustorium after 12^{th} week. On the other hand after 12^{th} week the dietary fibre which could not be digested becomes higher in content in the haustorium.

Once tubers start growing them produce starch from the sugars absorbed from the haustorium and save it inside for its growth as a plant. Therefore the starch content of Palmyrah tubers will increase while the plant produces its own food via photosynthesis. Later when the leaves sprout, starch is converted into simple sugars again and will be transferred to the upper part for their growth. Therefore the starch content in tubers will start decreasing at this stage.

CONCLUSION

The haustoriummust be harvested at 12^{th} week of growth to retain enough nutrients without affecting the traditional harvest yield of tuber with its optimum nutrient level. It is evident through this research that Palmyrah haustorium could improve the nutrient level in the consumer's body with proteins. Also, the soil type did not influence the changing pattern of the nutrient composition.

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