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Growth Modelling and Value Addition of Roselle (*Hibiscus sabdariffa*) Plant

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Abstract—*Hibiscus sabdariffa (Roselle plant) is a popular leafy vegetable in North-East India. A wide range of commercial products are derived from leaves and calyces. However, typically leaves are consumed but the other parts of the plants having great commercial potential is usually ignored. Through value addition, Roselle plant (9.26 kg) parts such as calyx (1.4 kg/plant), stem (4.26 kg/plant), leaves (3.6 kg/plant) and seeds (1.4 kg/plant) can be converted into a right mix of products like dried, jam, beverage, coagulant, dye, oil, pickle as well as anthocyanin, soluble dietary fibre and polyphenols to produce nutraceuticals to use the plant sustainably. To understanding the plant morphology and growth characteristic such as maturity of the plant, plant heights, number of branches per plant, stem diameter, seed weight, calyx weight, width and length, number of calyxes per plant, calyx emergence (in days), number of leaves per plant, flowering time (weeks after planting), leaf and stem weight etc has also been used as growth modelling. Adopting an appropriate plant growth model better harvesting and value addition strategies can be made to improve farmers income from processing of Roselle plant.*

Keywords: *Hibiscus sabdariffa, growth modelling, value addition.*

1. INTRODUCTION

In India, food manufacturing sector is getting stimulation from the demand from both national and global consumers. However, the food processing industry in the country is highly fragmented. Barring few large companies most of the manufacturers are very small and the manufacturing sector is disconnected from the food production sector. It is important to connect the two sectors not just management wise but also technologically. Proper harvesting strategy is required to make the value addition more market oriented. Small-scale farmers and manufacturers are unable to inspect the market upfront, therefore they are not getting correct value of the raw material they producing [1]. There is lack of grading and standardization of raw materials especially for horticulture crops that is contradictory to the optimal use of the horticultural produces. There is an increased demand of the food products with specific nutritional needs and other functional properties. To fulfill the gaps knowledge about entire range of value addition of a crop is required. One such knowledge generation exercise has been done for *Hibiscus sabdariffa* (Roselle plant).

Hibiscus sabdariffa (Roselle plant) grows well in many parts of India including North-East India due to the suitable geo-climatic conditions. However, the varieties vary. Generally, it grows to maturity within 4-8 months and can sustain well till 20°C. It is herbaceous plant traditionally used as leafy vegetables, herbal drinks, beverages, pickle, jams and also as herbal medicine [2].

There is a huge potential to grow and value add Roselle plant for the small farmers. The crop can contribute to the local economy through the concept of 100% value addition. However, to do that a holistic idea about the various products from the plant is necessary. Growth modeling of plant enables us to trial hypotheses and implements virtual experiments regarding plant growth processes that could otherwise be takings years in actual field studies [3]. Plant growth is based on the irreversible expansion of the whole organism and possess three primary phases: the initial phase of slow growth, the vigorous growth phase and, finally, the final phase of slow growth [4,5,6,7]. The plant growth is influenced by physical (abiotic) and biotic factors of the environment [8, 9]; and temperature, water, light, atmosphere compositions, soil factors are the major modifying environmental perturbations.

The plant growth model simulates the behavior of real crop by predicting the growth of its components, such as stems, flower, roots, leaf area, grains, number of buds and leaves; thereby predicting the final state of harvestable yield or total biomass and also the information about the plant growth and development (for example, plant height and growth rate). Empirical models use the experimental data and are usually expressed as regression equations (with one or a few factors) and are used for estimation of the final yield. The application of regression and correlation analysis has imparted an interpretation of the variables and their interactions that were related to the cropping systems. As of now, no report has been found regarding the growth modeling and value addition of Roselle (*Hibiscus sabdariffa*). Therefore, the objective of the present study was to develop an empirical model of growth of the plant Roselle and the methodology for value addition to it.

2. METHODOLOGY

Empirical models were developed using linear and non-linear regression. The exponential model was used for the proper approximation of the growth in the initial period. The regression and correlation analysis have provided an interpretation of the variables and their interactions. The data were collected from the previous studies that had been carried out by: (1) *Falusi et al. (2014)* [10] for the growth patterns with time with the parameters determined were the number of branches and plant height as function of the growth time. And (2) *Anyinkeng & Mih (2011)* [11] for the soil nutrient (NPK) supplementation on growth and biomass production of Roselle. The levels of the soil treatments were T1= Control, T2 = NPK 60 kg ha-1, T3 = NPK 120 kg ha-1 and T4 = NPK 180 kg ha-1. Numbers flower bud, diameter of fresh flower bud, fresh weight of flower bud, dry weight of flower bud, calyx dry weight and time to flowering are the parameters as function of the levels of the NPK (N = Nitrogen, P = Phosphorous and K = Potassium) treatment.

3. RESULTS AND DISCUSSION:

3.1 Growth Modelling:

The figure 1 shows the propagation of branches of one plant with respect to the growing time and the regression equation was y = 0.8697x1.1175 (y = number of branches, x = number of weeks). As can be seen (Table 1), the branch number was increased rapidly (non-linearly) with plant growth. The plant growers can determine/predict the desirable number of branches by using the developed regression equation since the Roselle stem is highly demanded for making of fibers/allied fibers of jute. The stem has the same commercial value in the world fiber market as the jute fibers. This plant is also widely cultivated in North – East India for making fibers and ropes from the stem. On the other hand, the increasing rate usually will decrease while getting maturity of plant. In this case, the increasing number of branches with the growing time can be derived from the following logistic population growth equation:

$$\frac{dN}{dt} = rN\left(\frac{K-N}{K}\right)$$

Where, N = number of branches, t = growth time, r = maximum growth rate of one branch, K = maximum N value.

The plant height (Figure 1) was increased linearly with the growing time as confirmed from the developed regression equation: y = 7.9613x - 8.06 (y = plant height, x = number of weeks). This information is very needed for the growers to predict the desirable harvesting time when the desired plant height is attained.

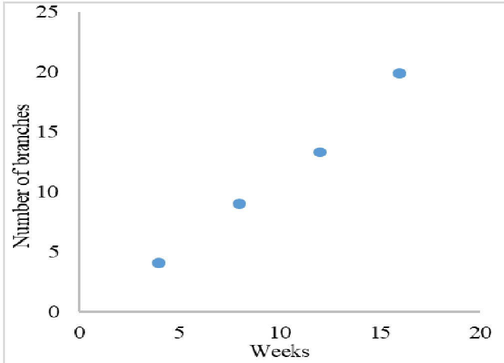

Figure 1: Plot of number of branches Vs growth time (weeks)

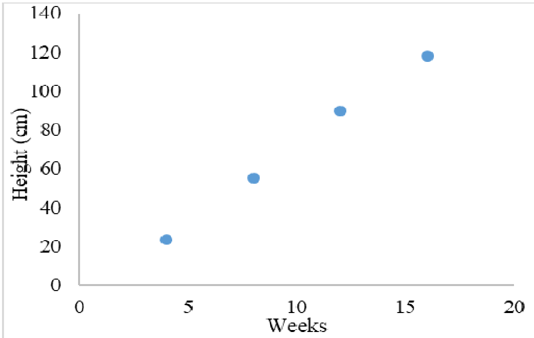

Figure 2: Plot of plant height Vs growth time (weeks)

The regression equations for the fresh weight of flower bud (Figure 3) and calyx dry weight (Figure 4) were found to be y = 1.6095e0.2538x (y = flower buds fresh weight, x = level of NPK treatment) and 0.117e0.3143x (up to level 3) (y = calyx dry weight, x = level of NPK treatment) (Table 2) respectively.

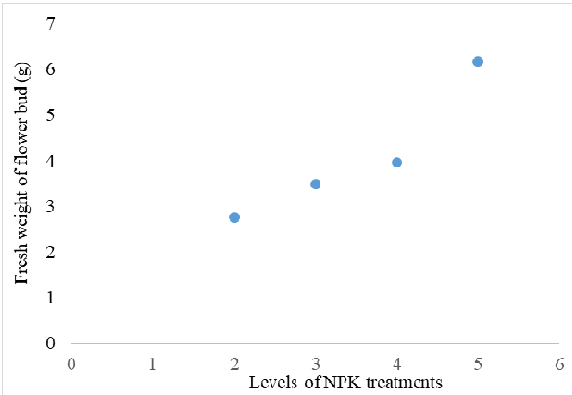

Figure 3: Plot of fresh weight of flower bud Vs levels of NPK treatments in the soil

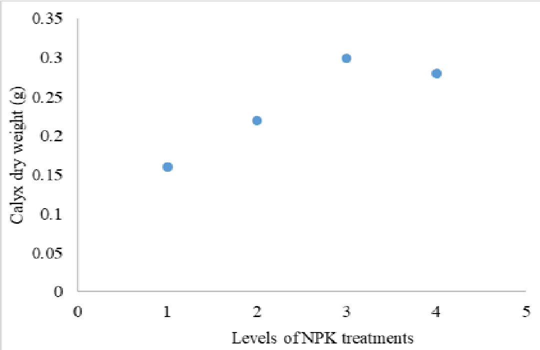

Figure 4: Plot of calyx dry weight Vs levels of NPK treatments in the soil

Table 1: Parameters of the Roselle plant with respect to soil treatments

Parameters	Regression equations
Dry weight of flower bud (g)	$y = 0.2202e^{0.2454x}$
Calyx dry weight (upto treatment level 3)	$0.117e^{0.3143x}$
Flower buds (no/plant)	$Y = 31.139x^{0.4013}$
Diameter of fresh flower bud (mm)	$y = 16.169e^{0.0959x}$
Fresh weight of flower bud (g)	$y = 1.6095e^{0.2538x}$
Dry weight of flower bud (g)	$y = 0.2202e^{0.2454x}$
Time to flowering (weeks)	$y = -1.2x + 18.2$
Diameter of fresh flower bud	$y = 2.216x + 15.004$

This indicates that the fresh weight of flower bud and the calyx dry weight were increased exponentially with increased of NPK concentrations in the soil. In the meantime, the calyx dry weight was decreased when the treatment level was higher than the level 4, indicating that the optimum level NPK treatment was essential for higher amount of calyx dry weight production. Many reports have also been informing that the simple exponential model may guarantee proper approximation of the growth in the initial period. It is convenient for all the farmers/plant growers/agriculturists to predict/calculate the desired quantity of flower bud fresh weight and calyx dry weight and NPK and their inter-relationships by using the above equations.

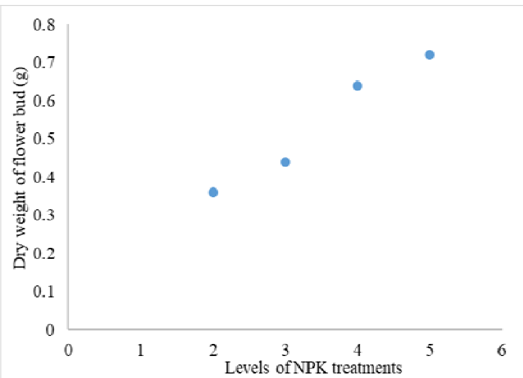

Figure 5: Plot of dry weight of flower bud Vs levels of NPK treatments in the soil

The regression equation of the diameter of fresh flower bud as function of the levels of NPK treatments in the soil was found to be $y = 2.216x + 15.004$ (y = diameter of fresh flower buds, x = level of NPK treatment) (Table 2). This equation implies that the higher concentrations of NPK linearly increased the diameter of fresh flower bud which is very beneficial for the agriculturists.

The figure 5 shows that the dry weight of flower bud was exponentially proportional to the higher NPK concentrations in the soil compositions, whereas the time to flowering (Figure 6) was linearly decreased. These combinations of relationships will help the farmers to understand how the soil composition will affect the yield of the plant Roselle. Many studies have revealed that the Roselle calyx and flower have many polyphenolic compounds (for example, anthocyanins) which are being used for many nutraceutical products.

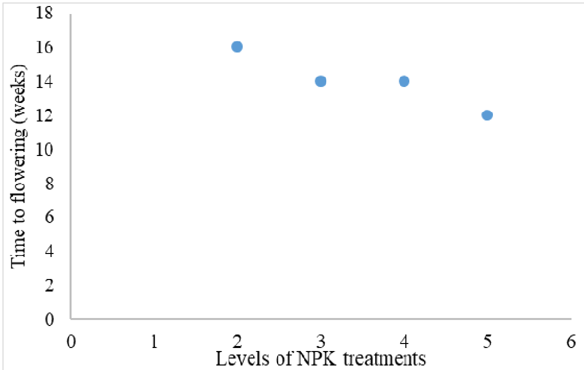

Figure 6: Plot of time to flowering Vs levels of NPK treatments in the soil

So, the higher calyx length and lesser flowering time are desirable for all the plant growers. They can predict the exact quantity of NPK to be incorporated with the soil in order to produce the desirable dry weight of flower bud and reduced flowering time by using the regression equations: y = 0.2202e0.2454x for dry weight of flower bud (x = level of NPK treatment, y= dry weight of flower bud) and $y = -1.2x + 18.2$ for flowering time (x = level of NPK treatment, y = time to flowering) (Table 2) respectively.

Table 2: Growth parameters of the Roselle plant with respect to time

Parameters	Regression equation
Number of branches	$y = 0.8697x^{1.1175}$
Plant height	$y = 7.9613x - 8.06$

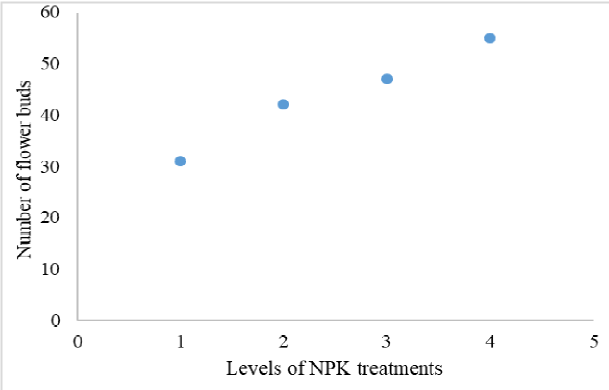

Figure 7: Plot of number of flower buds Vs levels of NPK treatments in the soil

The regression equation of the flower bud numbers (Figure 7) development as a function of the levels of the NPK treatments in the soil was y = 31.139x0.4013 (y = number of flower buds, x = level of NPK treatment) (Table 2).

It shows that the new flower buds of the Rosella were emerged very speedily, i.e., non-linearly with the growing time. This implies that a higher level of NPK in the soil favors the flower bud emergence and this equation is beneficial for the plant growers to predict the relationship between the flower bud's emergence with the NPK concentrations. The regression equation for the diameter of fresh flower bud as function of the levels of the NPK treatments (Figure 8) in the soil was found to be y = 2.216x + 15.004 (y = diameter of fresh flower bud, x = level of NPK treatment) (Table 2), which is a linear relationship.

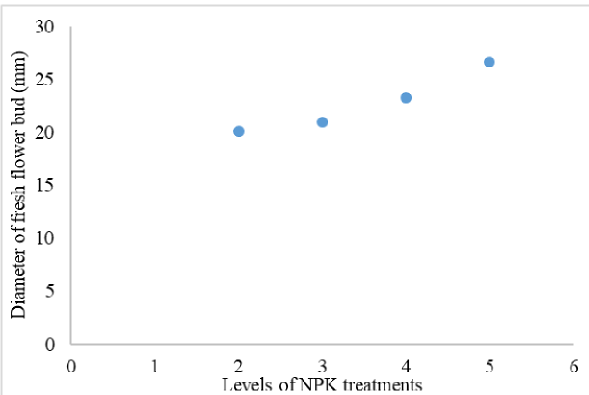

Figure 8: Plot of diameter of fresh flower bud Vs levels of NPK treatments in the soil

3.2 Value addition:

Before understanding or proceeding to the statistics of the value addition, it is necessary to understand the meaning of the value addition. Value addition "represents what a business adds to raw materials it purchases" (*Nichols and Goodwin*). Farmers or the manufacturer can add value through several methods such as use of different parts of plants and produce products through different processing. For example, here, the weight of the single roselle plant (9.26 kg) consists of leaf of 3.6 kg, stem of 4.26 kg, calyx of 1.4 kg, seeds of 1.4 kg which produces different products shown below [12 - 18] (Figure 9,10, 11, 12). The products mentioned (Table 3) for roselle plant will increase the presence of the product in the market and will highlight its characteristics like read to eat products, convenience and health.

The commercially available products (Table 4) is so far is based mostly on tea, beverages and pickle but with the increasing the products like dried leave (pickle industry), coagulant (paneer industry), coffee, spices, nutraceutical products (high anthocyanin content, soluble dietary fibre and polyphenols) and bast fibres (packaging industry) will increase the range and value of the raw materials. With these increase in value addition it will attract the food companies and will increase the agricultural production.

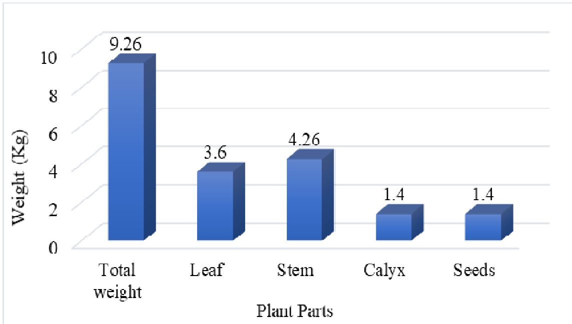

Figure 9: Yield of per plants

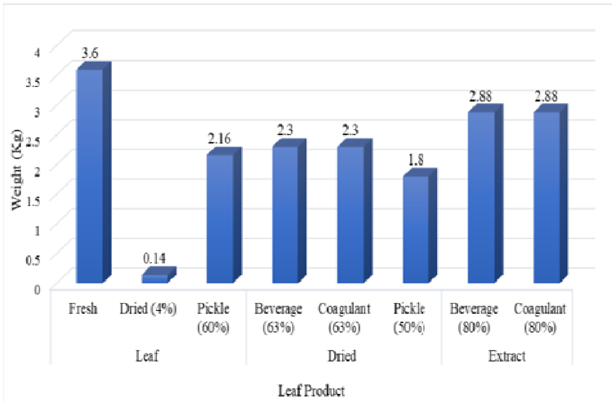

Figure 10: Yield of the leaf products

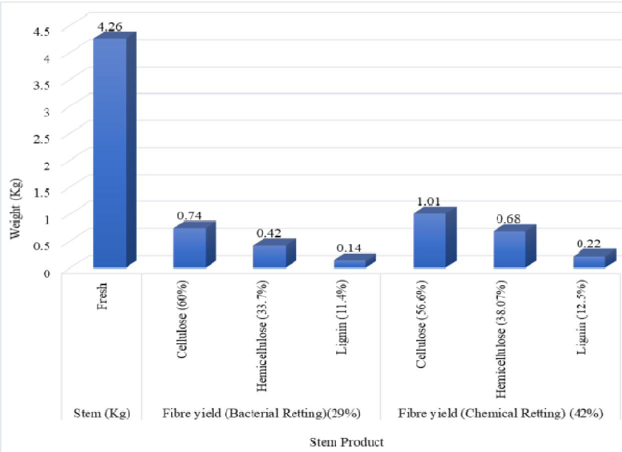

Figure 11: Yield of stem products

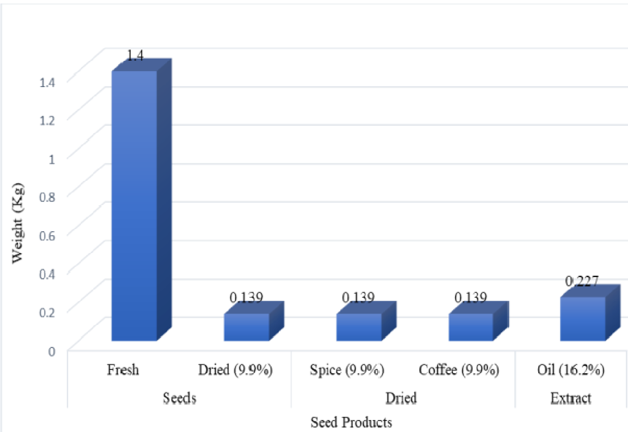

Figure 12. Yield of the seed products

Table 3. Yield of the Roselle products

Whole plant weight (9.26 kg)

Leaves (38.87%)	Calyx (15.11%)	Stem (46%)	Seeds (15.11%)
3.6	1.4	4.26	1.4

Leaves (3.6 kg)

Fresh (kg)			**Dried (kg)**			**Extract (kg)**	
Fresh	**Dried (4%)**	**Pickle (60%)**	**Beverage (63%)**	**Coagulant (63%)**	**Pickle (50%)**	**Beverage (80%)**	**Coagulant (80%)**
3.6	0.14	2.16	2.3	2.3	1.8	2.88	2.88

Calyx (1.4 kg)

Fresh (kg)		Dried (kg)										
								Extract (kg)				
Fresh	Dried (8%)	Beverage (80%)	Coagulant (80%)	Beverage (65%)	Coagulant (65%)	Jam (60%)	Dye (1.97%)	Beverage (80%)	Coagulant (80%)	Anthocyanin (2.52%)	Soluble dietary fibre (28%)	Polyphenols (66%)
1.4	0.112	1.12	1.12	0.91	0.91	0.84	0.03	1.12	1.12	0.035	0.39	0.924

Seeds (1.4 kg)

Seeds (kg)		Dried (kg)		Extract (kg)
Fresh	Dried (9.9%)	Spices (9.9%)	Coffee (9.9%)	Oil (16.2%)
1.4	0.139	0.139	0.139	0.227

Stem (4.26 kg)

Stem	Fibre yield (Bacterial Retting) (29%)			Fibre yield (Chemical Retting) (42%)		
Fresh	Cellulose (60%)	Hemicellulose (33.7%)	Lignin (11.4%)	Cellulose (56.6%)	Hemicellulose (38.07%)	Lignin (12.5%)
4.26	0.74	0.42	0.14	1.01	0.68	0.22

Table 4: Commercially available products

Sl. No.	**Product**	**Cost (Rs)**	**Weight (g)**	**Expiry (years)**	**Supplier**
1.	Hibiscus Tea (Flower Cut) Repacked in India	599	500	1.9	amazon.com
2.	Micro Roselle Hibiscus Powder (Poland)	4,104.03	30	1.8	ebay.com
3.	Roselle Flower Extract (China)	10710.00	1000	2	alibaba.com
4.	Roselle Flowers Tea (China)	407.69	40	2	dhgate.com
5.	Roselle Puree Drink Concentrate (Malaysia)	641.21	1 Litre	1.6	alibaba.com
6.	Roselle Jam (From Dried Roselle) (Philippine)	302.11	160	2	beautymnl.com
7.	Roselle Drink (Taiwan)	256.16	175	1	kingkung.en.taiwantrade.com
8.	Rosella Jam (Australia)	569.60	230	2	bushtuckershop.com

9.	Dry Roselle Flowers (India)	260	1000	1	indiamart.com
	Roselle Tea (Dried Roselle Calyces)	238.72	21	2	beautymnl.com
10.	Shinko Red Roselle Healthy Juice (Indonesia)	855.82	7000	2	21food.com
11.	Jyo's Farm Preservative Free Gongura Pickle	200	150	1	qtrove.com
12.	Future Organics Gongura Pickle (Pack Of 2)	350	320	1	qtrove.com
13.	Lakshmi's Andhra Pickles & Podis (Sorrel) Gongura Pickle	95	250	1/2	flipkart.com
14.	Just Pickled Jp_Gongura Gongura Pickle (India)	60	200	1	flipkart.com
15.	Gongura Pickle Garlic (India)	200	1kg	1/2	indiamart.com
16.	Holy Natural Hibiscus Sabdariffa Flower (Dried -Edible Grade) (India)	350	100 g	1	Amazon
17.	Chado Tea Hibiscus - Cut & Sifted Tea (India)	998	100 g	1/2	qtrove.com
18.	Hibiscus Flower (Sabdariffa) - By Nature's Gift - For Those Who Care's (India)	500	100 g	1	Amazon
19.	Wild Hibiscus Flowers In Syrup - 8.8 Oz (250 G) By Wild Hibiscus Flower Company (Australia)	993.88	250 g	2	Amazon
20.	Daylicious Whole Hibiscus Flowers (India)	499	250 g	3	Amazon
21.	Hibiscus Alcohol-Free Liquid Extract, Organic Hibiscus (Hibiscus Sabdariffa) Dried Flower Glycerite Hawaii Pharm Natural Herbal Supplement (Hawaii)	1346.25	120 ml	-	hawaiipharm.com
22.	Hibiscus Tea,Hot And Cold Tea, (Dry Roselle Flower Tea) By Holy Natural, Organically Grown By Holy Natural - The Wonder Of World (India)	851.79	113.4 g	1.3	Amazon
23.	Solaray, Hibiscus Flower Extract, (India)	951.88	15 g	3	iHerb
24.	Dr Roselle (Bangladesh)	3787.20	120 capsules	3	memoraglobal.com
25.	Dr Roselle Red Food (Bangladesh)	1683.20	400 g	-	memoraglobal.com
26.	Hibiscus Tea/Flower Dried (Roselle Or Roselle Flower) (Singapore)	710.42	250g	1	sg.carousell.com
27.	Organic Mamaki & Hibiscus (Hibiscus Sabdariffa) Tea (Hawaii)	1065.63	15 bags	-	hicommonscents.com
28.	Organic Hibiscus Sabdariffa-Roselle Seeds: Non-Gmo, 250+ Seeds (United States)	4,734.11	250 seeds	-	qoostore
29.	Australian Red Rosella Hibiscus Extract (Australia)	Not mentioned	500ml	2	botanicalinnovations.com.au
30.	Enzyme Roselle Preserved Fruit	483.65	130g	1.6	alibaba.com

4. CONCLUSION

Growth study of Roselle will provide an insight to the farmers and producers to cultivate the plant for different products or to understand the most feasible time to harvest the plant to get the best possible combination of plant parts (e.g., leaves, calyces, branches etc.) and their time of harvesting for commercially viable value addition. Through these, farmers can gain more profit the farm and can enhance the economy by better marketing practices. The standardization of the growth factors (parameters) and the appropriate strategy for the value addition of a plant like Roselle (*Hibiscus sabdariffa*) are highly recommended for better utilization of the plant.

5. CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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