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Comparative Morpho-Agronomic and Biochemical Profiling of Different Roselle Morphotypes Based on Their Growth and Yield Associated Attributes

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Abstract

When introducing a new, promising crop to an area, farmers can be assisted in selecting the crops and varieties that are most suitable for commercialization by doing an assessment of the yield characteristics. *Hibiscus sabdariffa* var. sabdariffa, as Roselle, is valued as a food crop for its great nutritional potential, vibrant pigment richness, and therapeutic significance. However, there is little information available because it is a very recent crop in Bangladesh. Finding the morphotype that performed the best given the yield characteristics was the study's main goal. Green plant with green calyx (WC), light red plant with light red calyx (LRC), and deep red plant with deep red calyx (DRC) were the performed morphotypes of Roselle. A number of morphological (plant height, stem perimeter, branches & capsule features etc.) and biochemical (total chlorophyll, carotenoid and phenolic content) were evaluated. For their yield characteristics, all morphotypes were noticeably distinct from one another. While plant height was identical in both LRC and DRC, DRC performed better in terms of capsules number produced per plant (av. 273.00 plant-1 capsules weighing 1779.10 g). Shelling ratio (% calyx to capsule) was also greater in DRC (av. 41.90%) than other two morphotypes. Dry matter content was greater in stem with branches and leaf, irrespective of morphotypes. Mature leaves of LRC had significant levels of total chlorophyll (1.34 mgg-1FW). In our study phenolic content reduced as capsule size increased in WC but not in LRC or DRC. In contrast to the other three morphotypes, the deep red plant with deep red calyx (DRC) performed the best, according to our study.

Keywords: Roselle morphotypes; Agro-morphological traits; Biochemical composition; Calyx yield quality; Comparative study.

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1. Introduction

Hibiscus sabdariffa var. sabdariffa, sometimes known as Roselle or Sorrel, is an annual flowering plant in the Malvaceae family that is cultivated primarily for its leaves, stem, seed, and calyces [1-5]. It is a source of natural antioxidants and micronutrients with culinary, nutritional, and therapeutic benefits [6-10]. For its antibacterial, antifungal, antiparasitic, anti-inflammatory, and antinociceptive qualities, Roselle is popular in the worldwide [11-17]. It has been discovered to be a good source of nutrients that are crucial for health from a nutritional standpoint [18-22]. Roselle has chemical constituents like anthocyanin, ascorbic acid, flavonoids, carbohydrates, organic acids, phenolic acid, pectin, mucilage, various type of volatile compounds, fat, hibiscin etc. [23, 24]. The structure of the canopy is crucial for all plants. The biomass yield is directly correlated with canopy structure [7, 9, 25, 26]. This plant is used as fiber crop, leaf vegetable and refreshing beverage from calyx [4, 14, 16, 20, 27]. Leaves extracts reported to contain protein, fat, carbohydrate, fiber, ash, calcium, phosphorus, iron, thiamine, β-carotene, riboflavin, niacin and ascorbic acid [28, 29]. There have been reports that hibiscetin 3-monoglucoside and various forms of methanolic extract can be found in hibiscus flowers and seeds [7, 9, 30]. This most usable part of Roselle plant may be green, light red or deep red calyx [31] which is enriched with anthocyanin, calcium, carbohydrate, carotene, iron, vitamin C, phenolic compounds, protein and traces of fiber [32, 33]. The green calyces are used for making vegetable stew [34]; while deep red and light red ones are utilized in preparing drinks, jellies, sauces, chutneys, wines, preserves and tea [7, 9, 35-37]. The biological properties of Roselle calyx, including its implications on atherosclerosis prevention [38], anticarcinogenic activities especially in the field of leukemia [39], cyclooxygenase inhibitory activities, chemo-preventive properties [40], hepatoprotective effects and antihypertensive effects [41] have been reported. The crop has undergone significant renovation and is now playing a larger role in the production of various small-scale industries, including the fabrication of cosmetics, tablets, jams, jellies, sweets, sauces, and cosmetics. Although experiments on morphology, growth, time of planting have been carried out [42, 43] in Bangladesh there are few published reports on morphotypes variation of Roselle in Bangladesh. International research on phytochemical investigations is available but there is lack of information in Bangladesh regarding this. There is no study related to total phenolic components and chlorophyll contents. The objectives of this study were to investigate variation in canopy structure and biomass yield; to find out the best one for yield and calyx quality, shelling ratio (% calyx to capsule) and dry matter content, as well as to find out some significant biochemical parameters (total chlorophyll, carotenoid, and phenolic content) in three Roselle morphotypes.

2. Materials and Methods

2.1. Location of the Study

The experiment was carried out between March 2020 and December 2021 at the experimental field, Physiology and Ecology Laboratory, Department of Crop Botany, Bangladesh Agricultural University, Mymensingh (24 75′ N and 90 50 ′ E), at an elevation of 18m above sea level.

2.2. Materials of the Experiments

Hibiscus sabdariffa var. sabdariffa has three distinct morphotypes: a green plant with a green calyx, identified by WC; a light red plant with a light red calyx, identified by LRC; and a deep red plant with a deep red calyx, identified by DRC. When the temperature (18–30°C) is favorable for the maturity of the leaf and calyx as well as the physiological maturation of the capsule, the leaf and capsules were collected between November and January. The Roselle leaf and calyx used in the experiment were both fresh and oven-dried.

2.3. Standard Establishment

From the Crop Botany Department's field laboratory, seeds of the three morphotypes were collected from the earlier experiment. In accordance with the Randomized Complete Block Design with three replications, seeds were manually sown in April 2020 in plots of each 4m x 4m size, keeping a spacing of 1m x 1m. The customary cultural practices were followed [42].

2.4. Experimental Details

2.4.1. Study of Morphological Traits and Biomass Yield in Three Roselle Morphotypes at the Fifth Month and the Seventh Month after Planting

For morphological investigation, three plants from each morphotype were randomly chosen. Plant height, stem base perimeter (10 cm above the ground level of the stem), total nodes, number of effective and ineffective branches (effective branch: contained at least one capsule; ineffective branch: contained no capsule), fresh weight of leaf and stem plus branch; fresh and oven dry weight of leaf and other plant parts, number of capsules plant-1 in main stem and primary branch, capsule weight plant-1, average height, and perimeter of capsule, mean fresh and sundry weight of capsule & calyces of three morphotypes were recorded.

2.4.2. Calyx Shelling Ratio and Dry Matter Determination in Three Roselle Morphotypes

In accordance with Chowdhury [42], capsules were harvested at physiological maturity. Depending on the calyx quality, capsules of each morphotype were divided into three categories: Premier, Standard, and Good. In this investigation, we divided the capsules into three categories based on the calyx quality. The finest capsule quality, Type 1 (Premier), has a larger dry matter content at physiological maturity, no spots, and no fungus infestation. Type 3 (Good) suggests tiny size with reduced amount of dry matter before or after physiological maturity, while type 2 (Standard) indicates spotted and infected capsule and relatively immature capsule after or before physiological maturity. The three morphotypes' calyces underwent the same processing. One kg capsules of each morphotype was separated into calyx and ovary, and weighed out. Shelling ratio (SR) was calculated as follows:

% SR= (Fresh wt. of calyx from 1 kg capsule / Fresh wt. of 1 kg capsule) * 100Dry matter (DM) of leaf and calyces (at PM) were determined from fresh samples in quadruplates in three morphotypes.

2.4.3. Determination of Chlorophyll, Carotenoid and Total Phenolic Content of three Morphotypes in Roselle

It was determined how much total phenolic was in small, medium, and large-sized capsules as well as how much total chlorophyll and carotenoid was in younger and mature leaves. These are crucial in assessing the plant's system for photosynthesizing. Total phenolic content was determined by the Folin-Ciocalteu method [44] and total chlorophyll-a, chlorophyll-b, total chlorophyll, and carotenoid content of leaves were determined by UV-VIS spectroscopy [45].

2.5. Statistical Analysis

The least significant difference (LSD) test at the 5% levels of probability was used to determine the significance of the differences between the treatments, and the analysis of variance was conducted using the F test (variance ratio) [46].

3. Results

3.1. Morphological Characteristics the Fifth Month and the Seventh Month after Planting

The three Roselle morphotypes showed significant variation in morphological characteristics. Compared to DRC and WC, LRC plants were taller (114.00 cm), however they produced fewer branches (3.0 plant-1 instead). In addition, LRC showed better performance (4.30 cm) for the circumference of the stem. However, fresh total biomass yield was higher in DRC and LRC than in WC (Table 1) at fifth months. Plant traits resembled one another more or less at seventh months. There were more effective branches at seven months in both WC and DRC, but node numbers varied significantly. DRC carried maximum number of nodes (619, plant^{-1}). Moreover, total number of epicalyx plus calyx was higher both in primary branch and main stem in DRC (321.8 and 12.90 plant^{-1}, respectively) (Table 2).

Table-1. Morphological traits and biomass yield the fifth month after planting of three morphotypes (White calyx, WC; Light red calyx, LRC and Deep red calyx, DRC) in Roselle (*Hibiscus sabdariffa* var. sabdariffa)

Morphotype	Plant height (cm)	Stem base perimeter (cm)	Branch Per plant (No.)	Fresh Biomass yield (g/plant)				Dry Biomass Yield (g/plant)			
				Stem & branches	Young leaf	All other leaf	Total	Stem & branches	Young leaf	All other leaf	Total
WC	76.33 c	3.80 b	4.00 b	65.55 b	15.62 b	59.60 b	140.77 b	16.27 b	2.16 b	8.98 c	27.41c
LRC	114.00 a	4.30 a	3.00 c	102.24 a	16.79 b	70.56 ab	189.59 a	20.29 a	2.38 b	12.31b	34.98 b
DRC	92.67 b	3.83 b	6.00 a	93.20 a	21.85 a	86.25 a	201.30 a	20.43 a	3.07 a	14.10 a	37.60 a
$LSD_{0.05}$	10.791	0.386	0.802	13.612	3.294	16.952	18.081	2.462	0.336	1.235	2.011
Sig. level	**	*	**	**	**	*	**	**	**	**	**
CV (%)	5.05	4.31	8.16	6.90	8.02	10.36	4.50	5.71	5.86	4.61	2.65

** = Significant at 1% level of probability, * = Significant at 5% level of probability

Table-2. Morphological traits and capsule yields at the seventh month after planting in three morphotypes (White calyx, WC; Light red calyx, LRC and Deep red calyx, DRC) in Roselle (*Hibiscus sabdariffa* var. sabdariffa)

Morphotype	Plant height (cm)	Stem base perimeter (cm)	Primary Branch						Main Stem			
			Effective branch (no.)	Ineffective branch (no.)	Nodes (no.)	Capsule Number			Nodes (no.)	Capsule Number		
						Imma.	Mature	Total		Immature	Mature	Total
WC	223.50 b	9.40 c	27.60 a	27.0 b	394.0 b	14.0 c	143.4 c	157.4 b	21.4 b	0.60 b	6.20 c	6.80 c
LRC	249.00 a	15.36 a	25.20 b	46.2 a	407.8 b	21.6 b	161.8 b	183.4 b	17.6 b	0.80 b	8.00 b	8.80 b
DRC	250.00 a	12.36 b	28.20 a	29.0 b	619.4 a	35.4 a	286.4 a	321.8 a	20.0 a	2.50 a	10.40 a	12.9 a
$LSD_{0.05}$	28.252	1.281	1.417	2.971	101.712	3.051	11.656	32.712	1.301	0.215	1.062	1.112
Sig. level	**	**	**	**	**	**	**	**	**	**	**	**
CV (%)	7.60	7.08	3.58	5.98	14.71	8.85	4.05	10.16	4.90	11.62	8.91	8.07

** = Significant at 1% level of probability, Imma. = Immature capsule

3.2. Capsule Yield and Quality at Harvesting Period

Three morphotypes showed substantial differences in capsule yield and quality (Table 3, 4) in Roselle. On average, a 273.00 number plant^{-1} and 1779.10 g plant^{-1} capsules were obtained from single plant of DRC and it was greater than others two (av. 997.45 g plant^{-1}). This showed that DRC had the greatest results in terms of capsule weight and number. DRC showed significant differences for capsule length. Mean capsule length was higher in all capsule type in DRC (5.08 cm, 4.67 cm and 4.06 cm for premier, standard and good, respectively) whether LRC & WC demonstrated better result for capsule perimeter than DRC.

Table-3. Capsule yield plant^{-1} of three morphotypes (White calyx, WC; Light red calyx, LRC and Deep red calyx, DRC) in Roselle (*Hibiscus sabdarifa* var. sabdarifa)

Morphotype	Capsule/plant (No.)	Fresh Capsule wt./plant (g)
WC	145.00b	899.90b
LRC	191.33b	1095.00b
DRC	273.00a	1779.10a
$LSD_{0.05}$	46.93	364.97
Level of significance	**	**
CV (%)	10.19	12.80

** = Significant at 1% level of probability

Table-4. Average length and premier of capsule in three morphotypes (White calyx, WC; Light red calyx, LRC and Deep red calyx, DRC) of Roselle (*Hibiscus sabdariffa* var sabdariffa) at seventh months after planting on basis of their calyx quality (premier, best quality; standard, medium quality and good, low quality of capsule, respectively)

Morphotype	Premier		Standard		Good	
	Length (cm)	Perimeter (cm)	Length (cm)	Perimeter (cm)	Length (cm)	Perimeter (cm)
WC	4.35 b	7.95 a	4.20 b	7.91 a	3.13 b	6.06 a
LRC	3.93 c	7.79 a	3.26 c	7.00 b	2.93 b	6.13 a
DRC	5.08 a	6.37 b	4.67 a	6.33 c	4.06 a	4.71 b
$LSD_{0.05}$	0.123	0.278	0.256	0.252	0.226	0.327
Sig. level	**	**	**	**	**	**
CV (%)	2.97	4.03	6.74	3.79	7.17	5.99

** = Significant at 1% level of probability,

3.3. Calyx Yield and Shelling Ratio on Basis of their Quality

All genotypes differed significantly from one another in terms of calyx yield and shelling ratio (% calyx to capsule) (Table 5). For premier, standard, and good type capsules, DRC shown superior results for calyx dry weight (avg. 0.23g Capsule-1) and shelling ratio (avg. 41.90%) compared to the other two. However, WC is comparatively better than LRC for this two attributes. LRC produced less shelling ratio in premier, standard and also in good type capsule (av. 34.11 %).In addition, shelling ratio was higher in premier than in standard and good type capsule among in WC, LRC and DRC (av. 39.02%, 38.40% and 37.52%, respectively). Here, premier type referred best quality capsule than standard and good one.

Table-5. Mean calyx dry weight capsule^{-1} of three morphotypes (White calyx, WC; Light red calyx, LRC and Deep red calyx, DRC) in Roselle (*Hibiscus sabdariffa* var. sabdariffa) at seventh months after planting on basis of their calyx quality (premier, best quality; standard, medium quality and good, low quality of capsule, respectively)

Morphotype	Weight Capsule^{-1}(g)											
	Premier				Standard				Good			
	Capsule fresh wt.	Calyx fresh wt.	Calyx dry wt.	Shelling Ratio (%)	Capsule fresh wt.	Calyx fresh wt.	Calyx dry wt.	Shelling Ratio (%)	Capsule fresh wt.	Calyx fresh wt.	Calyx dry wt.	Shelling Ratio (%)
WC	6.40b	2.52b	0.24b	39.36b	5.80b	2.27b	0.22b	39.14b	3.29b	1.30b	0.12b	38.29a
LRC	5.70c	1.98c	0.19c	34.68c	4.20c	1.43c	0.14c	34.13c	2.02c	0.68c	0.06c	33.52b
DRC	6.80a	2.92a	0.29a	43.03a	6.40a	2.66a	0.27a	41.94a	3.50a	1.43a	0.14a	40.75a
$LSD_{0.05}$	0.190	0.175	0.020	2.88	0.176	0.160	0.022	1.801	0.124	0.124	0.016	3.873
Sig. level	**	**	**	**	**	**	**	**	**	**	**	**
CV (%)	1.28	3.08	3.63	3.26	1.42	3.22	4.43	2.08	1.81	4.70	6.35	4.55

** = Significant at 1% level of probability

3.4. Dry Matter Content of Plant Parts

Plant stem and branch, matured leaf and calyx were dried and data were analyzed at 5% level of probability (Table 6). Dry matter content of stem & branches, leaf and calyx were significant in 1% level of probability. Dry matter content in stem and branch was higher both in DRC and WC (av. 23.35%) than LRC (av. 19.77%) where LRC and DRC produced higher amount of leaf dry matter content (av. 16.26%). Dry matter content of calyx in WC, LRC and DRC was similar (av. 10.16%) and not significant. Regardless of morphotype, stem, branch, and leaf often had higher dry matter contents.

Table-6. Dry matter content of stem and branch, leaf and calyx of three morphotypes (White calyx, WC; Light red calyx, LRC and Deep red calyx, DRC) in Roselle (*Hibiscus sabdarifa* var. sabdarifa)

Morphotype	Dry matter (%)		
	Stem & branch	Leaf	Calyx
WC	24.57 a	14.74 b	10.27
LRC	19.97 b	16.76 a	10.16
DRC	22.12 ab	15.75 ab	10.06
$LSD_{0.05}$	2.875	1.301	0.475
Sig. level	**	**	NS
CV (%)	5.71	3.66	2.07

** = Significant at 1% level of probability

3.5. Total Chlorophyll and Carotenoid Content of Roselle

Three morphotypes of Roselle's younger and mature leaves were examined, and we discovered significant variations in the amount of chlorophyll ($P \leq 0.05$). (Fig. 4.1-4.4). Total content of Chlorophyll-a was high in LRC and Chlorophyll-b content was high in DRC mature leaf (av. 1.02 mg g^{-1} FW and 0.315 mg g^{-1} FW, respectively) where WC younger leaf produced lowest amount. Total chlorophyll content was higher in mature leaf of LRC (1.34 mg g^{-1} FW) than mature leaf of other morphotypes WC and DRC (av. 1.11 mg g^{-1} FW). Chlorophyll content of younger leaf in three morphotypes was similar. However, total carotenoid content was higher and similar in mature leaf (0.173 mg g^{-1} FW) than younger leaf (0.129 mg g^{-1} FW) of all morphotypes. This showed that in three morphotypes, older leaves had higher total chlorophyll and carotenoid levels than younger leaves.

Figure-1. Variation of chlorophyll-a in younger and mature leaf of three morphotypes (White calyx, WC; Light red calyx, LRC and Deep red calyx, DRC) in Roselle (*Hibiscus sabdarifa* var. sabdarifa). Each bar represents average of three replication ± SEM. In each group, bars sharing different letters are significantly different from each other at P ≤ 0.05

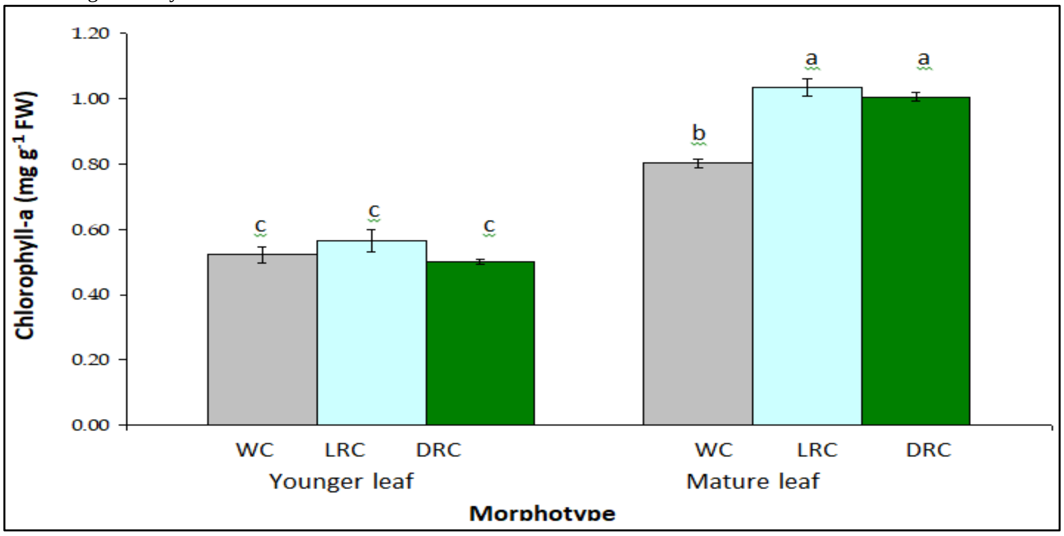


Figure-2. Variation of chlorophyll-b in younger and mature leaf of three morphotypes (White calyx, WC; Light red calyx, LRC and Deep red calyx, DRC) in Roselle (*Hibiscus sabdarifa* var. sabdarifa). Each bar represents average of three replication ± SEM. In each group, bars sharing different letters are significantly different from each other at P ≤ 0.05

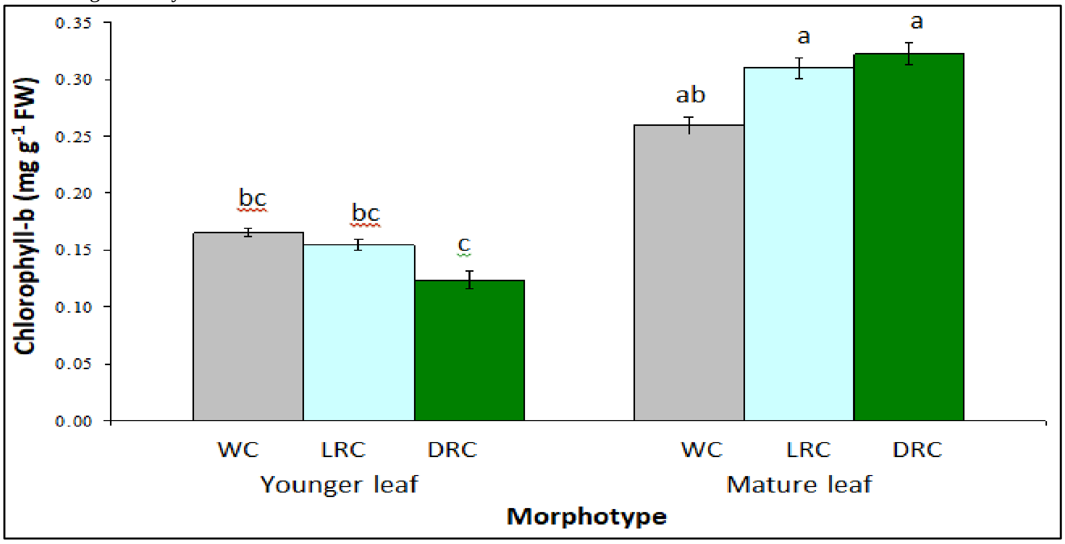


Figure-3. Variation of total chlorophyll content in younger and mature leaf of three morphotypes (White calyx, WC; Light red calyx, LRC and Deep red calyx, DRC) in Roselle (*Hibiscus sabdarifa* var. sabdarifa). Each bar represents average of three replication ± SEM. In each group, bars sharing different results are significantly different from each other

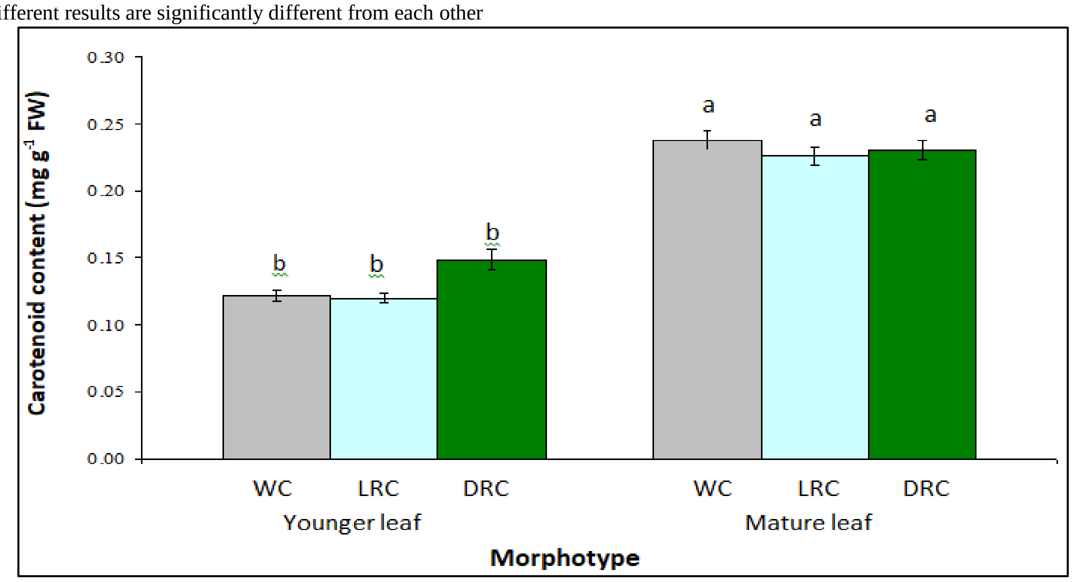
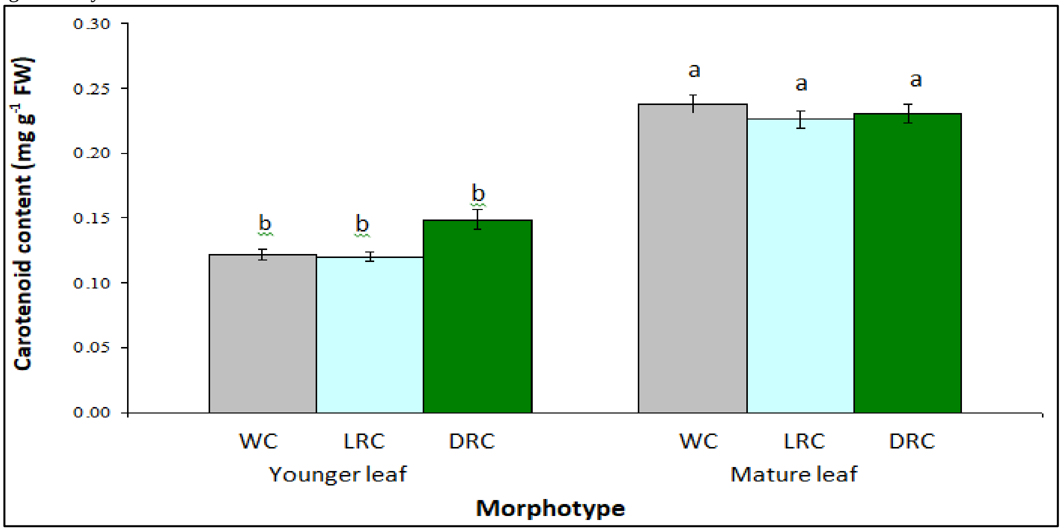


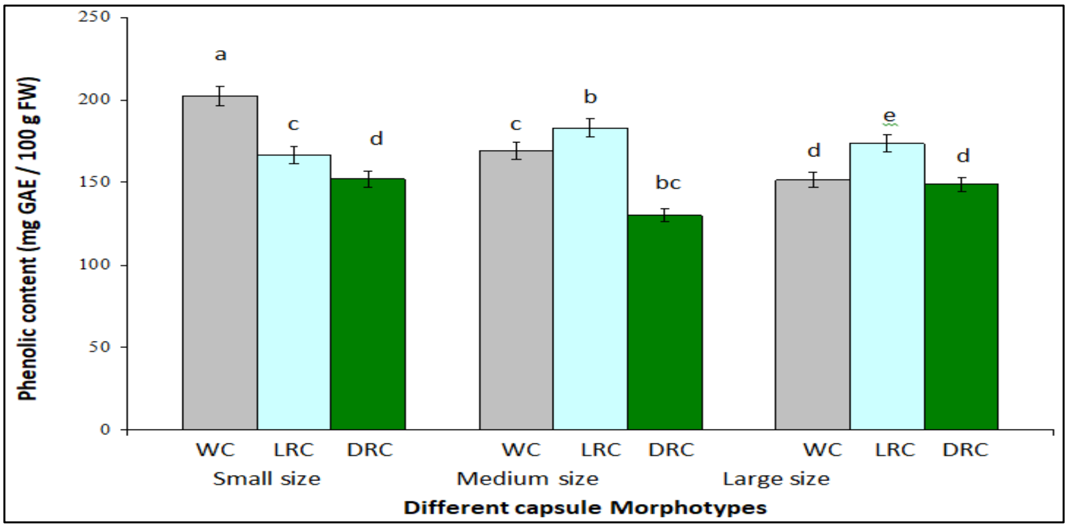
Figure-4. Variation of carotenoid in younger and mature leaf of three morphotypes (White calyx, WC; Light red calyx, LRC and Deep red calyx, DRC) in Roselle (*Hibiscus sabdarifa* var. sabdarifa). Each bar represents average of three replication ± SEM. In each group, bars sharing different letters are significantly different from each other at P ≤ 0.05



3.6. Total Phenolic Content of Roselle

Total phenolic content was significantly different among three morphotypes of Roselle at significant level (P ≤0.05) (Fig.5). Small size capsule of WC contained higher amount of phenolic content (202.30 mg GAE/100 g FW) than others where medium size capsule of DRC had lowest amount (130.10 mg GAE/100 g FW). There was an interesting difference among the morphotypes. Total phenolic content decreased with the increasing of capsule size in WC where medium size capsule of LRC contained higher amount (183.10 mg GAE/100 g FW) and medium size capsule of DRC contained lower amount of phenolic content (130.10 mg GAE/100 g FW). However, the result clearly indicated that total amount of phenolic contents decreased with the increasing of capsule size in WC but not in LRC and DRC.

Figure-5. Variation of total phenolic contents in different size capsule of three morphotypes (White calyx, WC; Light red calyx, LRC and Deep red calyx, DRC) in Roselle (*Hibiscus sabdarifa* var. sabdarifa). Each bar represents average of three replication ± SEM. In each group, bars sharing different letters are significantly different from each other at P ≤ 0.05



4. Discussion

Roselle (*Hibiscus sabdariffa* L.) is a comestible plant known for its anti- bacterial, diuretic, anti-oxidant, and anti-mutagenic effects. [1, 8]. It is high in vitamins, minerals and bioactive substances such as organic acids, phytosterols, and polyphenols, and because of its extensive pharmacological potential [47-49]. In Bangladesh it is not so popular. The assessment of morpho agronomic and biochemical variability is of great importance for using any efficient selection method in order to improve the population. Yield attributes are also very much important for its commercialization.

The observed differences among these morphotypes can be attributed to genetic as well as to environmental factors. All morphotypes were significantly different from each other for their yield attributes. LRC showed better performances for both plant height and stem base perimeter (Table 1). But effective branches and total nodes number per plant were high in DRC. Similar result was obtained from Terengganu variety (alike with DRC) of Roselle [49]. Total dry biomass yield of stem and branches was found higher in LRC and DRC than WRC in our study but scientist Mara concluded African Green Roselle yielded the highest dry weight of stem and branches [49]. This variation may be attributed due to genetics as well as to environmental and cultural practices [50]. Results from Table 3 showed that each plant had higher fruits number and weight in DRC (273.00 number plant^{-1} and 1779.10 g plant^{-1}; respectively) than WC and LRC (av. 168.16 number plant^{-1} and av. 997.45 g plant^{-1}; respectively) indicating a good genetic variation. Such a variation could be due to differences in genotype, environment and cultural practices [46, 49, 50]. Another researcher found that UKMR-2 showed better performances for weight of fruits per plant (2170.70 g) in Roselle [46]). There were some findings in our experiment that mean height per capsule was higher in DRC but mean perimeter was higher and more or less similar in WC and LRC (Table 4). Similar observation was demonstrated by Javedzadeh where he concluded that Red calyx was long and higher than other variety [4]. Harvestable portion of the flower i.e. magnitude of calyces to fruit (shelling ratio) was also important. The Shelling ratio (% calyx to capsule), was higher in premier type capsule (av. 39.02%) than standard and good in all morphotypes (av. 38.40 % and av. 37.52 %, respectively) (Table 5). Our result indicated that premier type capsule was better than standard and good one for higher dry mater content and shelling ratio indicating PM was the best period for capsule harvesting. Among these three morphotypes, in our result, DRC showed better performance for shelling ratio (Table 5). Dry matter (DM) or moisture content is also important for preservation of calyx. The DM in the current experiment appeared higher in stem and branch than leaf and calyx irrespective to morphotypes (Table 6). There was no significant variation in DM content of calyx in three morphotypes. But according to scientist Osman dry mater content of UKMR1 (like LRC) showed significant difference than other varieties UKMR-2 (like DRC) and UKMR-3 (like WC) [51]. The observed difference among these results could be attributed due to genetics as well as to environmental factors, such as nutritional contents in soil, irrigations, temperatures etc.

Total chlorophyll contents indicated the photosynthetic quality which is responsible for dry matter accumulation [52]. As calyx is our main interest and edible parts, so it is our concern for higher amount of dry matter. In this experiment we have analyzed younger and mature leaf of three morphotypes. Our observation showed mature leaf contained more chlorophyll and carotenoid content than younger leaf. Where total chlorophyll content was higher in Light red mature leaf than others (Fig. 4.3). However, total chlorophyll content varied in difference published literatures due to variation in experiment design, stress factors [53]; variations in soil potentials [52]; effects of irrigations [54]; use of bio fertilizers [55] and others.

The phenolic compound of Roselle varies between morphotype to morphotype and one geographical area to another [48, 56, 57]. The two accessions with the highest total phenolic compound content were from Ghana (PI286316) and Senegal (PI275413) [47]. So all of these references indicated the health important of phenolic content of Roselle.

In our study, phenolic content was determined from small, medium and large sized capsules in three morphotypes (WC, LRC, and DRC). However, these data were not comparable with published literature due to variations in i) morphotypes; ii) weight basis (in our case fresh weight basis) [53], iii) phenolic contents due to stress [52] and iv) environmental variations [54]. All three morphotypes contained a good amount of phenolic content.

5. Conclution

The morphotypes varied significantly in terms of both biochemical measurements and morphoagronomic characteristics. Our study led us to the conclusion that DRC and LRC were taller plants than WC, with DRC performing better in respect of total biomass production, effective branches, and plant^{-1} nodes (Tables 1, 2). Additionally, the primary edible portion, which refers to the capsule and calyx yield, was also found to be abundant in the DRC (Tables 3, 4). DRC shown higher results for primer, standard, and good type capsules in terms of calyx dry weight and shelling ratio (avg. 0.23g Capsule^{-1} & avg. 41.90%, respectively). Here, "premier type" refers to the highest grade capsule for its highest shelling than in the standard and good one. Another finding of our research concerned dry matter. In comparison to leaf dry matter, which was high in LRC (av. 16.07%) but stem and branch dry matter was high in WC (av. 24.57%). However, the mature leaf of LRC had a high total chlorophyll content (1.34 mg g-1 FW), whereas phenolic levels declined as capsule size increased in WC but not in LRC or DRC. From our entire research work we can conclude that DRC (Deep red calyx with capsule) performed better.

Data Availability

All the necessary data are included in the manuscript. If additional data are required, the corresponding author can be contacted.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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