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# Growth, Yield and Shattering Dynamics of Seeds of Twelve Roselle (*Hibiscus sabdariffa* L.) Accessions

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author PKT designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors BKB and IAI managed the analyses of the study. Author EAG managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

Roselle (*Hibiscus sabdariffa* L.) is an important crop grown in tropical and subtropical climates with huge nutritional, economic and industrial benefits. The plant undergoes explosive shattering to disperse seeds after physiological maturity leading to high loss of seeds at the time of harvesting. A field experiment was carried out to determine the effect of different harvesting stages on the growth, yield and shattering dynamics of seeds of twelve Roselle accessions in the Department of Horticulture, Kwame Nkrumah University of Science and Technology, Kumasi from March to November, 2019. A 3x12 factorial design in Randomized Complete Block Design (RCBD) was used for the study, where factor one was harvesting stages at three levels (physiological maturity, one week after physiological maturity and two weeks after physiological maturity) and factor two was accessions at twelve levels. The study revealed that accession HS08 performed best in terms of growth (plant height, the number of leaves, number of branches and stem girth) and reproductive parameters (number of days to flowering) and accessions HS27 and HS08 produced the highest yield (number of pods, number of seeds per pod, and total seed yield). Harvesting of seeds at the physiological maturity stage happened to be the ideal time because seeds were harvested safely without any losses (0%) due to shattering as compared to the other harvesting stages. The study also established a very strong, positive and significant relationship between seed yield and number

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of leaves (r=0.7093) and the number of branches (r=0.9241). However, there was a strong but negative and significant relationship between seed yield and percentage seed shattering loss (r=-0.9633). There was a very strong, positive and significant relationship between number of leaves and stem girth (r=0.7769). The number of seeds per plant correlated positively with the number of pods (r=0.7358). A regression model which was given by the equation; Y (Seed yield)=670.96-0.3152 (Shattering loss), $R^2$=0.9279, p<0.0000, indicated that shattering loss significantly affected seed yield to an extent that it contributed 93% of the variation in the seed yield.

*Keywords: Germplasm; morphological characteristics; physiological maturity; quality seed and viability.*

## 1. INTRODUCTION

Roselle (*Hibiscus sabdariffa* L.) is an annual shrub belonging to the family Malvaceae and its origin is believed to be tropical Africa or Asia [1], where it was first found in the wild and later domesticated for its leaves and seeds. Roselle is known in different countries by various common names including Roselle, Razelle, Sorrel, Soursour and queens land jelly plant [2]. Economic parts of the Roselle are calyces rich in anthocyanins and protocatechuic acid. The dried calyx contain the flavonoids gossypetine, hibiscetine and sabdaretine. The major pigment formerly reported as hibiscine has been identified as daphniphylline [2]. Recently the sepal extract has been used as an effective treatment against leukemia due to its high content in polyphenols particularly protocatechuic acid [3]. Substantial wealth is also derived from the bast fiber of Roselle in India, Southeast Asia, Russia, Kenya, Nigeria, Sudan, Italy, and Cote D'Ivoire [4-6]. Bast fiber made from the plant is used in the manufacture of carpets, automobile and airplane upholstery yarn, burlap, rope and paper [7]. Gradually, the leaves and fleshy calyxes of Roselle are used as vegetables in the African countries, i.e. Ghana, Nigeria, Senegal, Burkina Faso, Mali, and Cote D'Ivoire [8].

The plant undergoes explosive shattering to disperse seeds shortly after physiological maturity leading to high loss of seeds at the time of harvesting. Research report of Indira and Dharmalingam, [9] indicated that seed quality can also be limited by environmental conditions both before and after physiological maturity, the stage of development at which the seed possesses its maximum dry mass. Environmental conditions during seed development and maturity including temperature, water stress or excessive rain, nutrients shortage, diseases infection, and pest attack influence seed quality of Roselle [10]. The germplasm of the many accessions of the Roselle are unfortunately exhibited at the CSIR-Plant Genetic Resource Institute, Ghana's foremost plant genetic resources conservation Centre [11] which is seen as a threat to biodiversity conservation. The lack of genetic resource conservation of a plant has negative impacts on research and development activities of the plant for economic exploitation. Seeds gradually attain viability and vigor during the developmental process as seed dry weight is accumulated. Maximum seed quality may be achieved at the end of seed filling period [12]. Stage of maturity at harvest is one of the most important factors that can influence the quality of seeds [13]. Harvesting too early may result in low yield and quality, because of the partial development of essential structures of seeds [14]. Whereas, harvesting too late may increase the risk of shattering and decrease the quality of seeds due to aging. There are a number of research information on how harvesting stages affect the seed yield in some crops like soya bean (*Glycine max*), rice (*Oryza sativa*) and cowpea (*Vigna unguiculata*) [15-17] however, little is known about Roselle. The main objective of this study was to evaluate the growth, yield and shattering characteristics of seeds of twelve accessions of Roselle harvested at different stages.

## 2. MATERIALS AND METHODS

### 2.1 Study Site

The study was conducted at the Department of Horticulture, Kwame Nkrumah University of Science and Technology- KNUST, Kumasi from March to October, 2019. The site is in the semi-deciduous forest zone with an elevation of 186m above the mean sea level (MSL) and a bimodal rainfall distribution. The major rainy season in the study area is lasting from late March to mid-July. There is a short dry spell from mid-July to mid-September followed by the minor rainy season from mid-September to mid-November. The mean annual rainfall is 1500 mm. The mean minimum and maximum temperatures are $21^0$C and 31°C, respectively. The mean annual relative humidity is 95% in the morning and about 60% at noon. The soil at the experimental site is ferric Acrisol.

## 2.2 Seeds Collection and Screening

Germplasm were collected from Roselle growing communities in the three northern regions, Volta region and some parts of Brong Ahafo region of Ghana to obtain a representative collection of seeds of different Roselle accessions. The seeds were first screened on the field for establishing morphological similarities among the collected accessions. Twelve accessions were chosen after screening for this experiment.

## 2.3 Experimental Plot Design and Procedure

The field experiment was set up in a Randomized Complete Block Design (RCBD) with three replications and 12 accessions as treatments. At the stage of harvesting the experimental design was 12x3 factorial arrangements in RCBD. The first factor comprised of accessions at 12 levels. The second factor was harvesting times at three levels (harvesting at physiological maturity, harvesting one week after physiological maturity and harvesting two weeks after physiological maturity). The land was manually prepared using the zero tillage method. Seeds were planted in three central rows for data collection. Each row was 5 m long at spacing of 60 cm between rows and 30 cm within rows. The distance between replicates was 1 m. Three seeds were planted per hill and thinned to two, two weeks after planting. Weeds were effectively controlled during the growing period. Monitored spraying was carried out at four and six weeks after planting with Lambda Super 2 SEC to control insect pests. Harvesting at physiological maturity was carried out when 90% of the pods on the plant turned from green to brown and the sepals started to dry.

## 2.4 Parameters Studied

### 2.4.1 Fifty percent field emergence

Four middle rows were selected from eight rows for data collection. Seedlings emerged were counted daily from the day of first seedling emergence until the day 50% of the seedlings emerged. The total number of days was then recorded as the number of days to 50% emergence for the treatment.

### 2.4.2 Measurements of plant growth and seed yield

Five plants were randomly selected from the four middle rows of each plot and tagged for the assessment of plant height, number of branches per plant, number of pods per plant and number of seeds per plant.

### 2.4.3 Height of the plant

Plant height (cm) was measured from the base to the growing tip of the plant using a meter -scale. Measurement was done at two weeks intervals.

### 2.4.4 Number of branches per plant

The number of branches per plant was determined by counting at physiological maturity.

### 2.4.5 Days to 50% flowering

Four middle rows were selected for the measurement of the number of days to 50% flowering. Counting started from the day the first plant flowered until the day 50% of the plants flowered. The total number of days was then recorded as the number of days to 50% flowering for the treatment.

### 2.4.6 Number of pods per plant

The number of pods per plant was counted at physiological maturity. The mean values were then calculated and recorded.

### 2.4.7 Number of seeds per plant

The number of seeds per plant was counted at physiological maturity after which the mean values were calculated and recorded.

### 2.4.8 Seed yield

Two rows were used to evaluate the seed yield of each varietal harvesting stage. A total of two hundred and four (204) stands of Roselle were used. After harvesting, threshing was done to remove the seeds from the pods. Collected seeds were then weighed to assess the seed yield (g).

### 2.4.9 Percentage of seed shattering loss

Shattering loss of seed was determined by counting all loose seeds and seeds in loose pods on the ground. The number of seeds that shattered was collected on a daily basis after observing first shattering on the field. The number of seeds that shattered was weighed using an analytical digital balance, and the percentage of shattering loss was determined from the total seed yield.

### 2.4.10 Percentage of seed purity

A representative sample of 500 g weight from each plot was separated into three components (pure seed, other crop seed and inert matter) through visual assessment [18]. Those components were then weighed and the proportional percentage of each component was determined and recorded accordingly [19].

**Plate 1. Roselle plant at the physiological maturity stage with seed pod turning brown (captured by authors)**

**Plate 2. Roselle plant at one week after physiological maturity stage (captured by authors)**

**Plate 3. Roselle plant at two weeks after physiological maturity stage (captured by authors)**

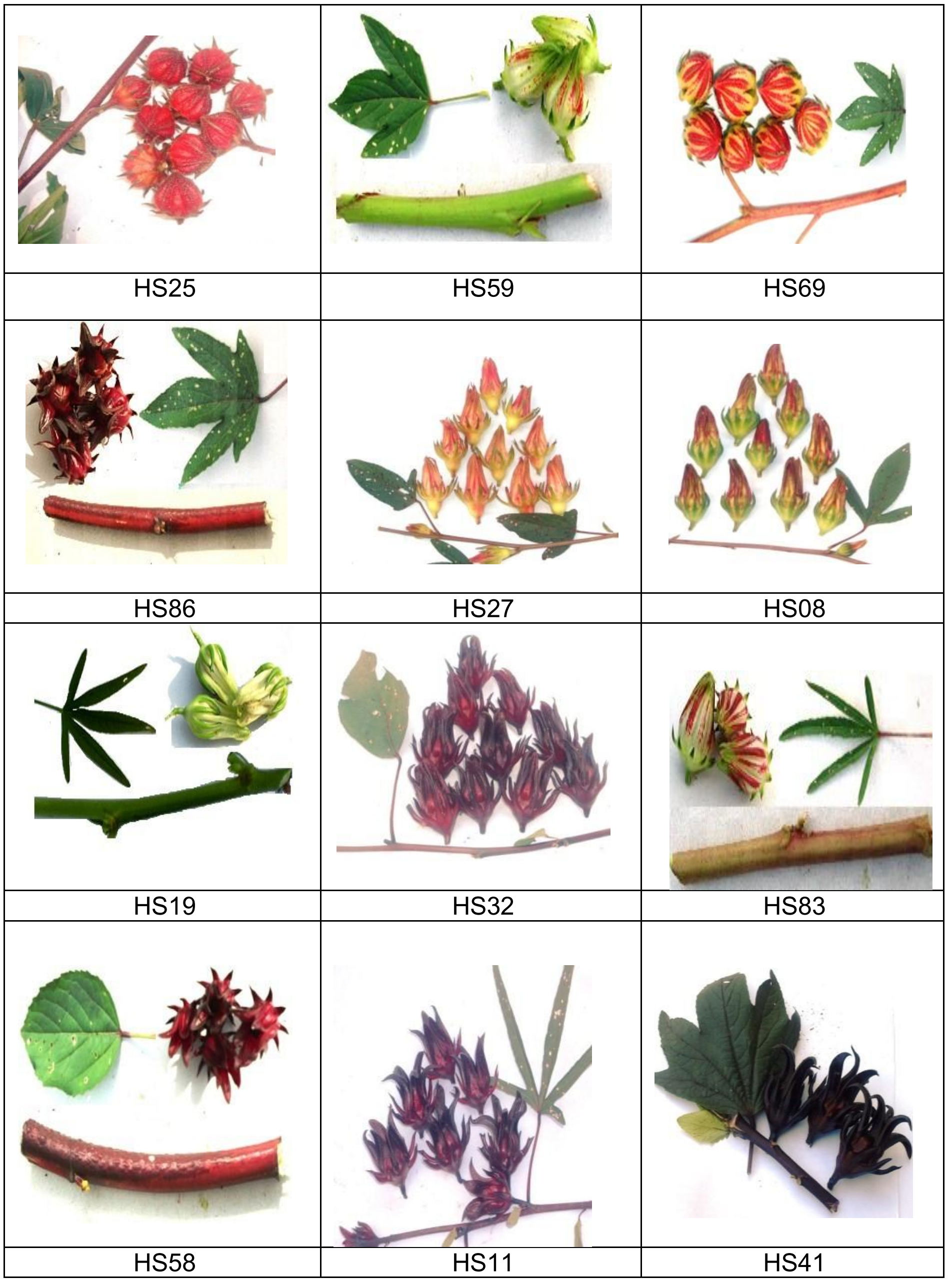


**Plate 4. Morphological description of different accessions used for the study (captured by authors)**

### 2.5 Data Analysis

All the collected data were gathered carefully and subjected to Analysis of Variance (ANOVA) using Statistics Version 10.0. Tukey's HSD (Honest Significant Difference) test was used for mean separation at probability level of 0.05. Relationship analyses (correlation and regression models) were also established for certain related variables.

## 3. RESULTS

### 3.1 Climatic Information of Experimental Period

The average monthly weather data, presented in Table 1 was collected at the study site during the study and covered the period from April 2019 to December 2019. The highest rainfall was recorded during the month of April (280.1mm).

The lowest rainfall data (16.7mm) was recorded during the month of December 2014. Monthly temperatures during the same period range from the lowest (22.7ºC) recorded in September 2014 to the maximum temperatures (32.8ºC) recorded in December 2014 (Table 1).

## 3.2 Growth, Seed Yield and Shattering Characteristics of Roselle Accessions

### 3.2.1 Number of days to emergence and plant height at four and six weeks after transplanting of different Roselle accessions

This study revealed that there were significant differences ($p$<0.05) between the accessions for seedling emergence, plant height at four and six weeks after sowing (Table 2). It took approximately five days for the seedlings of all the accessions to emerge except accessions HS69 and HS25 which took six days to emerge. HS69 and HS25 were however not significantly different from HS27 in relation to the number of days to seedling emergence. Accession HS83 being the tallest plant (30.80 cm) was significantly different from Accession HS86 (30.10 cm) at four weeks after sowing (Table 2). The least plant height of 27 cm was recorded by HS27 and HS58 respectively. At six weeks after sowing, accession HS83 produced the tallest plants (92.40 cm) which was 1.34 times taller than the shortest plants (81.00) produced by accessions HS27 and HS58 respectively but was not significantly different from HS86 (90.53 cm).

### 3.2.2 Plant height of different Roselle accessions at eight, ten and twelve weeks after sowing

From the study, it was observed that there were significant differences (p<0.05) between the accessions for plant height at eight, ten and twelve weeks after sowing (Table 3). Significantly (p<0.05) tallest plants (184.80 cm) at eight weeks after sowing was accession HS83 which was similar to accession HS86 (180.73 cm). The shortest plants (161.67 cm) were recorded by HS27 and HS58 (161.67 cm). At ten weeks after sowing accession HS83 produced the tallest plants (189.13cm) which was 1.14 times taller than the shortest plants produced by accessions HS27 and HS58 respectively. At 12 weeks after sowing, both accessions HS83 and HS86 recorded the highest plant height and the least was accessions HS27 and HS58.

### 3.2.3 Number of leaves of different Roselle accessions at four, eight and twelve weeks after sowing

Results showed that there were significant differences ($p$<0.05) between the accessions for number of leaves at four, eight and twelve weeks after sowing (Table 4). Significantly, highest number of leaves (7.33) at four weeks after sowing was accession HS08 which was similar to HS27 (7.00). The least number of leaves (5.00) was recorded by HS86, HS19 and HS69. At eight weeks after sowing, accessions HS08 and HS27 produced the highest number of leaves (14.00) and the least number of leaves (10.00) was recorded by HS86, HS19 and HS69 respectively. At twelve weeks after sowing, accessions HS08 and HS27 produced the highest number of leaves (28.67) and the least number of leaves (20.00) was recorded by HS86, HS19 and HS69 respectively.

### 3.2.4 Stem girth of different Roselle accessions at four, eight and twelve weeks after sowing

There were significant differences ($p$<0.05) between the accessions for stem girth at four, eight and twelve weeks after sowing (Table 5). Significantly, highest stem girth (1.57 mm) at four weeks after sowing was accession HS08. The least stem girth (5.00 mm) was recorded by accessions HS86, HS11, HS41, HS19, HS25, HS59 and HS69. At eight weeks after sowing, accessions HS08 produced the highest stem girth (3.03 mm) and the least stem girth was recorded by accessions HS86, HS11, HS41, HS19, HS25, HS59 and HS69. At twelve weeks after sowing, accessions HS08 continued to produce the highest stem girth (4.7 mm) and least stem girth was recorded by accessions HS86, HS11, HS41, HS19, HS25, HS59 and HS69.

### 3.2.5 Number of branches and days to 50% flowering of different Roselle accessions

There were significant differences ($p$<0.05) between the accessions for number of branches at weeks six, ten and number of days to flowering (Table 6). Accessions HS86, HS19, HS59, HS27 and HS58 produced the highest number of branches at week six while accessions HS83, HS11, HS32 produced the least. For number of branches at week ten, highest branches (12.67) were recorded by accession HS08 and accession HS83 recorded the least (7.00). For the number of days to 50% flowering, it took about 55 days for accession HS83 to flower while it took 64 days for accession HS59 to flower.

### 3.2.6 Number of pods per plant, seeds per pod and percentage purity of Roselle accessions

There were significant differences ($p<0.05$) between the accessions for number of pods per plant, seeds per pod and percentage purity (Table 7). For number of pods per plant, accession HS83 recorded the highest number of pods per plant (16 pods) and the least was recorded by HS32 and HS59 (12 pods). Accession HS83 had the highest number of seeds per pod (16) and accessions HS27 and HS58 had the least (13). The highest percentage purity for all the accessions was 97%, except accession HS25 which recorded the least purity (95%).

### 3.2.7 Effect of harvesting stages on seed yield of different Roselle accessions

The result of the study showed that interactions between harvesting stages and Roselle accessions for seed yield were significant ($p<0.05$) (Table 8). Highly significant seed yield (555.00 g) was produced by accessions HS08 and HS27 and which were harvested at the physiological maturity stage and was 1.11 times more than the least seed yield (498.33 g). The least seed yield was produced by accession HS83 which was harvested at two weeks after physiological maturity. Among the accessions, the highest seed yield was produced by HS08, followed by HS27, HS25 and HS86, and the least seed yield was produced by accession HS83. With respect to the harvesting times, Roselle seeds harvested at physiological matured stage produced significantly highest seed yield (551.28g) and the least (501.67 g) was produced by those harvested at two weeks after physiological maturity stage.

### 3.2.8 Effect of harvesting stages on seed shattering loss (%) of different Roselle accessions

The interactions between harvesting stages and Roselle accessions were significant ($p<0.05$) for seed shattering loss (%) (Table 9). Significantly highest seed loss due to shattering was recorded by HS58 which was harvested two weeks after physiological maturity stage (26%), and was similar to accessions HS25, HS86, HS32, HS69, HS11 and HS19 which were harvested at physiological maturity stage. The lowest shattering loss (%) was recorded by all the twelve accessions which were harvested at the physiological maturity stage. Among the accessions, the highest percentage seed shattering loss was HS11 and the least was HS08 and HS83. Between harvesting stages, Roselle seeds harvested at physiological matured stage produced significantly least percentage seed shattering loss (0%) and the highest percentage shattering loss (23.08%) was produced by seeds harvested at two weeks after physiological maturity stage.

**Table 1. Monthly Weather data of the study site in the year 2019**

| Monthly Weather Data for March-November, 2019 | | | |
|---|---|---|---|
| **Months (2019)** | **Rainfall (mm)** | **T* max. (ºC)** | **T* min. (ºC)** |
| March | 280.10 | 28.10 | 24.20 |
| April | 132.50 | 30.10 | 24.40 |
| May | 264.90 | 28.30 | 23.80 |
| June | 113.00 | 29.50 | 23.90 |
| July | 92.00 | 30.50 | 23.80 |
| August | 206.50 | 28.90 | 22.70 |
| September | 173.30 | 31.20 | 23.40 |
| October | 139.00 | 31.60 | 23.80 |
| November | 16.70 | 32.80 | 22.90 |

**T: Temperature (in degree Celsius)*

*Source: Weather Station, KNUST, Kumasi.*

**Table 2. Plant height (cm) of different Roselle accessions at four and six weeks after sowing**

| Accessions | Number of Days to Emergence | Plant height 4WAS* | Plant height 6WAS* (cm) |
|---|---|---|---|
| HS83 | 4.67b | 30.80a | 92.40a |
| HS86 | 4.67b | 30.10a | 90.53a |
| HS08 | 4.67b | 29.00b | 87.00b |
| HS11 | 4.67b | 29.00b | 87.00b |
| HS41 | 4.67b | 29.00b | 87.00b |
| HS69 | 5.67a | 29.00b | 87.00b |
| HS19 | 4.67b | 28.00c | 84.00c |
| HS25 | 5.67a | 28.00c | 84.00c |
| HS32 | 4.67b | 28.00c | 84.00c |
| HS59 | 4.67b | 28.00c | 84.00c |
| HS27 | 5.33a | 27.00d | 81.00d |
| HS58 | 4.67b | 27.00d | 81.00d |
| HSD* (0.05) | 0.495 | 0.891 | 2.663 |

** WAS= Weeks after Sowing; HSD*= Honest Significant Difference*

**Table 3. Plant height (cm) of different Roselle accessions at eight, ten and twelve weeks after sowing**

| Accessions | Plant height 8WAS | Plant height 10WAS* | Plant height 12WAS* |
|---|---|---|---|
| HS83 | 184.80a | 189.13a | 193.80a |
| HS86 | 180.73a | 184.40a | 189.07a |
| HS08 | 173.67b | 177.33b | 182.00b |
| HS11 | 173.67b | 177.33b | 182.00b |
| HS41 | 173.67b | 177.33b | 182.00b |
| HS69 | 173.67b | 177.33b | 182.00b |
| HS19 | 167.67c | 171.33bc | 176.00bc |
| HS25 | 167.67c | 171.33bc | 176.00bc |
| HS32 | 167.67c | 171.33bc | 176.00bc |
| HS59 | 167.67c | 171.33bc | 176.00bc |
| HS27 | 161.67d | 165.33c | 170.00c |
| HS58 | 161.67d | 165.33c | 170.00c |
| CV | 1.14 | 1.31 | 1.28 |
| HSD (0.05) | 5.817 | 6.801 | 6.801 |

** WAS= Weeks after Sowing; HSD= Honest Significant Difference*

**Table 4. Number of leaves of different Roselle accessions at four, eight and twelve weeks after sowing**

| Accessions | No. of leaves at 4WAS* | No. of leaves at 8WAS* | No. of leaves at 12WAS* |
|---|---|---|---|
| HS83 | 6.00b | 12.00b | 24.00b |
| HS86 | 5.00c | 10.00c | 20.00c |
| HS08 | 7.33a | 14.00a | 28.67a |
| HS11 | 6.00b | 12.00b | 24.00b |
| HS41 | 6.00b | 12.00b | 24.00b |
| HS69 | 5.00c | 10.00c | 20.00c |
| HS19 | 5.00c | 10.00c | 20.00c |
| HS25 | 6.00b | 12.00b | 24.00b |
| HS32 | 6.00b | 12.00b | 24.00b |
| HS59 | 6.00b | 12.00b | 24.00b |
| HS27 | 7.00a | 14.00a | 28.00a |
| HS58 | 6.00b | 12.00b | 24.00b |
| HSD* (0.05) | 0.495 | 0.485 | 0.989 |

** WAS= Weeks after Sowing; HSD= Honest Significant Difference*

**Table 5. Stem girth (mm) of different Roselle accessions at four, eight and twelve weeks after sowing**

| Accessions | Stem girth at 4WAS* (mm) | Stem girth at 8WAS* (mm) | Stem girth at 12WAS* (mm) |
|---|---|---|---|
| HS83 | 1.43ab | 2.87ab | 4.30ab |
| HS86 | 1.23c | 2.47c | 3.70c |
| HS08 | 1.57a | 3.03a | 4.70a |
| HS11 | 1.23c | 2.47c | 3.70c |
| HS41 | 1.23c | 2.47c | 3.70c |
| HS69 | 1.23c | 2.47c | 3.70c |
| HS19 | 1.23c | 2.47c | 3.70c |
| HS25 | 1.23c | 2.47c | 3.70c |
| HS32 | 1.33bc | 2.67bc | 4.00bc |
| HS59 | 1.23c | 2.47c | 3.70c |
| HS27 | 1.43ab | 2.87ab | 4.30ab |
| HS58 | 1.23c | 2.47c | 3.70c |
| HSD* (0.05) | 0.198 | 0.247 | 0.594 |

** WAS= Weeks after Sowing*
*HSD= Honest Significant Difference*

**Table 6. Number of branches and days to 50% flowering of different Roselle accessions**

| Accessions | Branches at 6 WAS* | Branches at 10 WAS* | Days to 50% flowering |
|---|---|---|---|
| HS83 | 3.67c | 7.00d | 54.67i |
| HS86 | 5.67a | 11.33b | 57.67g |
| HS08 | 4.67b | 12.67a | 56.67h |
| HS11 | 3.67c | 7.33d | 56.67h |
| HS41 | 4.67b | 9.33c | 61.67c |
| HS69 | 4.67b | 9.33c | 57.67g |
| HS19 | 5.67a | 12.00ab | 58.67f |
| HS25 | 4.67b | 9.33c | 60.33de |
| HS32 | 3.67c | 7.33d | 60.67d |
| HS59 | 5.67a | 11.33b | 63.67a |
| HS27 | 6.00a | 12.00ab | 59.67e |
| HS58 | 5.67a | 11.33b | 62.67b |
| HSD* (0.05) | 0.495 | 1.146 | 0.990 |

** WAS= Weeks After Sowing*
*HSD= Honest Significant Difference*

**Table 7. Number of pods per plant, seeds per pod of Roselle accessions**

| Accessions | Pods per plant | Seeds per pod | Purity (%) |
|---|---|---|---|
| HS83 | 16.00a | 16.00a | 97.00a |
| HS86 | 15.00b | 14.67b | 97.00a |
| HS08 | 12.00e | 12.67d | 97.00a |
| HS11 | 13.00d | 12.67d | 96.00b |
| HS41 | 14.00c | 13.67c | 97.00a |
| HS69 | 13.00d | 13.67c | 96.00b |
| HS19 | 14.00c | 13.67c | 97.00a |
| HS25 | 14.33c | 13.67c | 95.00c |
| HS32 | 12.00e | 13.67c | 97.00a |
| HS59 | 12.00e | 13.67c | 97.33a |
| HS27 | 13.00d | 12.67d | 96.00b |
| HS58 | 13.00d | 12.67d | 96.00b |
| HSD* (0.05) | 0.495 | 0.495 | 0.495 |

*HSD= Honest Significant Difference*

**Table 8. Effect of harvesting stages on seed yield (g) of different Roselle accessions**

| Accessions | Physiological Maturity | Harvesting times | | Means |
|---|---|---|---|---|
| | | One week after physiological maturity | Two weeks after physiological Maturity | |
| HS08 | 555.00a | 532.33de | 502.33fg | 529.89a |
| HS27 | 555.00a | 532.33de | 502.33fg | 529.89a |
| HS25 | 552.33ab | 533.33d | 503.33f | 529.67a |
| HS86 | 552.33ab | 533.33d | 503.33f | 529.67a |
| HS32 | 551.33abc | 532.33de | 502.33fg | 528.67ab |
| HS69 | 551.33abc | 532.33de | 502.33fg | 528.67ab |
| HS11 | 550.33abc | 531.33de | 501.33fg | 527.67ab |
| HS19 | 550.33abc | 531.33de | 501.33fg | 527.67ab |
| HS41 | 550.33abc | 531.33de | 501.33fg | 527.67ab |
| HS59 | 550.33abc | 531.33de | 501.33fg | 527.67ab |
| HS58 | 549.33bc | 530.33de | 500.33fg | 526.67bc |
| HS83 | 547.33c | 528.33e | 498.33g | 524.67c |
| Means | 551.28a | 531.67b | 501.67c | |
| HSD* (0.05): Accessions=2.351, Harvesting times=0.833, Accessions*Harvesting times=4.823 | | | | |

*HSD= Honest Significant Difference*

**Table 9. Effects of harvesting stages on seed shattering loss (%) of different Roselle accessions**

| Accessions | Physiological Maturity | Harvesting times | | Means |
|---|---|---|---|---|
| | | One week after physiological maturity | Two weeks after physiological Maturity | |
| HS08 | 0.00d | 11.00c | 21.00ab | 10.67b |
| HS27 | 0.00d | 16.00bc | 21.00ab | 12.33ab |
| HS25 | 0.00d | 13.00c | 26.00a | 13.00ab |
| HS86 | 0.00d | 11.00c | 26.00a | 12.33ab |
| HS32 | 0.00d | 13.00c | 26.00a | 13.00ab |
| HS69 | 0.00d | 16.00bc | 21.00b | 12.33ab |
| HS11 | 0.00d | 16.00bc | 26.00a | 14.00a |
| HS19 | 0.00d | 11.00c | 26.00a | 12.33ab |
| HS41 | 0.00d | 16.00bc | 21.00ab | 12.33ab |
| HS59 | 0.00d | 16.00bc | 21.00ab | 12.33ab |
| HS58 | 0.00d | 11.00c | 26.00a | 12.33ab |
| HS83 | 0.00d | 16.00bc | 16.00bc | 10.67b |
| Means | 0.00c | 13.83b | 23.08a | |
| HSD (0.05): Accessions=2.747, Harvesting times=0.973, Accessions*Harvesting times=5.635 | | | | |

*HSD*= Honest Significant Difference*

**Table 10. Correlation among some growth and yield parameters of Roselle seed**

| Correlation variables | Correlation coefficient | Probability level (5%) |
|---|---|---|
| leaves and height | -0.1968 | 0.5398 |
| leaves and stem girth | 0.7769 | 0.0029 |
| leaves and seed yield | 0.7093 | 0.0098 |
| height and stem grith | 0.1653 | 0.6077 |
| height and seed yield | -0.3262 | 0.3008 |
| branches and seed yield | 0.9241 | 0.0000 |
| stem girth and seed yield | 0.4036 | 0.1932 |
| pods and seeds per plant | 0.7358 | 0.0064 |
| Seed yield and shattering loss | -0.9633 | 0.0000 |

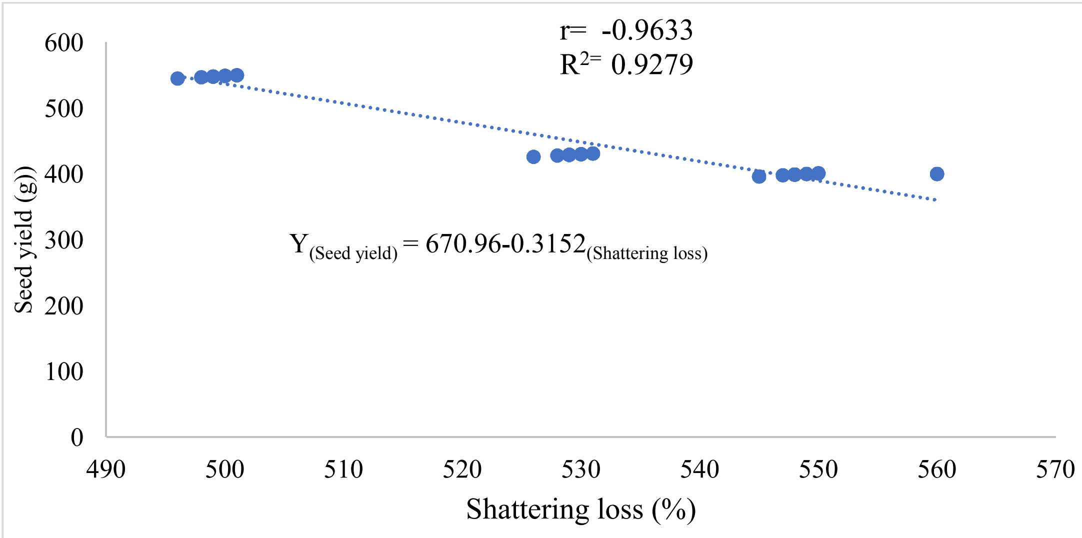


**Fig. 1. Linear regression analysis between seed yield and shattering loss (%)**

## 3.3 Relationship among Growth and Yield Parameters of Roselle Seed

### 3.3.1 Correlation among some growth and seed yield parameters

Findings of the study revealed a strong, positive and significant relationship between seed yield and other two parameters, e.g. number of leaves (r=0.7093), number of branches (r=0.9241). However, there was a strong but negative and significant ($p$<0.05) relationship between seed yield and percentage seed shattering loss (r=-0.9633). Furthermore, there were very strong, positive and significant relationship between number of leaves and stem girth (r=0.7769). There were also very strong, positive and significant relationship between seeds per plant and number of pods (r=0.7358) (Table 10).

### 3.3.2 Regression relationship between seed yield and percentage shattering loss

A linear regression between shattering loss (%) and yield of seed showed that shattering loss significantly influenced seed yield in such a way that 93% variation in the seed yield was attributed to the shattering loss (Fig. 1).

## 4. DISCUSSION

## 4.1 Growth, Seed Yield and Shattering Characteristics of Roselle Accessions

The significant variations among the accessions for seed emergence and other growth parameters such as plant height, number of leaves, branches and stem girth at the various weeks could be due to the genetic differences that exist among them. Productions from the accessions (HS83 and HS86) performed well in terms of the growth characteristics than the rest of the accessions. Ibrahim and Hussein [19] reported the significant differences among genotypes for seed emergence and other growth parameters. The results of the present study supported the findings of Gasim and Khaddir [20] where the researchers also reported that there were much genetic variability in Roselle accessions which affect their growth attributes. Environmental conditions could also influence the growth behavior of the different accessions in this study. A research conducted by Javadzadeh, and Saljooghianpour [21] indicated that environmental factors such as light, climate, soil conditions and rainfall could greatly influence the growth behavior of the Roselle plant. Such finding therefore suggests that both genetic and environmental variations affected the growth of the accessions used in this study. The research findings of Abou El-Nasr et al. [22], reported significant main effects of genotypes x environment for fifteen Sudan Roselle genotypes. There were significant differences ($p$<0.05) between the accessions for number of pods per plant, seeds per pod and percentage purity. For number of pods per plant, accession HS83 recorded the highest number of pods per plant (16 pods) and the least was recorded by HS32 and HS59 (12 pods). This could also be attributed to the genotypic variations that exist among the accessions used for the study. Correlation analysis also showed that there was a strong, positive and significant ($p$<0.05) relationship between number of leaves and stem girth (r=0.7769). This means that increasing number of leaves have influences on the increment of the stem girth.

## 4.2 Effects of Harvesting Stages on Seed Yield of Different Roselle Accessions

The results of this study showed that there were significant ($p$<0.05) interactions among harvesting stages and Roselle accessions for seed yield. Highly significant seed yield (555.00g) was produced by accessions HS08 and HS27and which were harvested at the physiological maturity stage and the least seed yield (498.33g) was produced by accession HS83 which was harvested at two weeks after physiological maturity. This was because harvesting at physiological maturity had the highest seed yield in all the accessions whilst harvesting two weeks after physiological maturity recorded the lowest yield. These findings confirmed the report of Vasudevan and van Staden [23] that harvesting of the seed crop at physiological maturity is better as seeds will be having maximum dry weight, higher viability and vigour, besides higher seed yield and yield attributing parameters. Boudreaux and Griffin [24] also stated that leaving soybean plants in the field past maturity exposes seed to adverse weather conditions that can reduce yield and quality. Furthermore, the huge genetic variability exhibited in the different Roselle accessions could also be the cause of the differences in seed yield. The results of the current study corroborate with the findings of Atta et al. [25], where the researchers stated that genotypic variability existed among the Roselle accessions assessed for their seed yield attributes.

There were very strong, positive and significant ($p$<0.05) relationship between seed yield and number of leaves (r=0.7093), number of branches (r=0.9241). In the present study, it showed that number of leaves and branches affect the seed yield. Similar findings were reported by Zaimoglu et al. [26] on how growth parameters positively correlate with seed yield. The number and growth of branches are also influenced by factors such as genotype and agricultural management [27,28]. Again, the branches of crops are developed from axillary buds. The gene expression of the low-branching cultivars regulating axillary bud development is low, and the number of plant branches finally formed is smaller, while the genes that regulate the development of axillary buds in multi-branching cultivars were active, and more branches were formed in the end [29]. In addition, light quality is also an important factor affecting the development of axillary buds. The axillary bud development of soybean was inhibited under low light condition, which can reduce branch number [30].

Moreover, there were very strong, positive and significant ($p$<0.05) relationship between seeds per plant and number of pods (r=0.7358). Increasing pod number increased seed yield and number of seeds per plant because this study revealed that there were very strong, positive and significant relationship between seeds per plant and number of pods (r=0.7358). This result supports the findings of Xu et al. [30] who reported of increasing branching and pod number increases seed number in soya bean.

## 4.3 Effects of Harvesting Stages on Seed Shattering Loss (%) of Different Roselle Accessions

Late harvesting may increase the risk of shattering and decrease the quality of seeds due to aging [31,14]. The present study revealed that delaying harvesting by one and two weeks after physiological maturity resulted in 26% shattering loss of the total seed weight. According to the report of Antwi-Bosiako [32], if certain seed crops (like soya beans) are left on the field after the pods are dry, the seeds may shatter, especially in the north where the dry winds can speed up the shattering process. Dong and Wang [33] reported the genetic basis of seed shattering in certain crops and that probably could be the reason why differences existed between the accessions in terms of seed shattering. Study also revealed that the highest percentage seed shattering loss was HS11 and the least was HS08 and HS83. A linear regression showed that shattering loss significantly influenced the seed yield in such a way that 93% variation in the seed yield was attributed to the shattering loss. Such findings suggested that the higher the shattering, the lower the seed yield per the accession. Similar relationships have been reported by Stephenson et al. [34]. The results of the current study also indicated that a strong but negative and significant relationship between seed yield and percentage seed shattering loss (r=-0.9633). This study will provide information for the sustainable production of roselle seeds with no seed losses.

## 5. CONCLUSION

This study revealed that accession HS08 performed best in terms of growth (plant height, number of leaves, number of branches and stem girth) and reproductive parameters (number of days to flowering) and accessions HS27 and HS08 produced the highest yield (number of pods, number of seeds per pod and total seed yield). Harvesting of seeds at the physiological maturity stage happens to be the ideal time because seeds were harvested safely without any loss of seeds (0%) due to shattering as compared to harvesting two weeks after physiological maturity which lead to about 26% loss of seed. The study also established a very strong, positive and significant ($p$<0.05) relationship between seed yield and number of leaves (r=0.7093) and number of branches (r=0.9241). However, there was a strong but negative and significant relationship between seed yield and percentage seed shattering loss (r= -0.9633). Number of leaves correlated positively and stem girth (r=0.7769). There were also very strong, positive and significant relationship between seeds per plant and number of pods (r=0.7358). A regression model given by the equation; $Y_{(Seed\ yield)}=670.96-0.3152_{(Shattering\ loss)}$, $R^2=0.9279$, $p<0.0000$, indicated that shattering loss significantly affected seed yield to an extent that it contributed 93% of the variation in the seed yield.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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