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RESEARCH ARTICLE

Moisture dependent physico-mechanical and aerodynamic properties of roselle calyxes (*Hibiscus sabdariffa*)

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ABSTRACT

The design of compatible harvesting and post-processing equipment as well processing techniques require information on the physical, mechanical and aerodynamic properties of agricultural materials. Therefore, this study focused on determination of some moisture dependent mechanical and aerodynamic properties of a dark red variety of roselle calyxes. Experiments were conducted to measure some physico-mechanical and aerodynamic properties of the roselle calyxes (such as dimensions, porosity, true and bulk density, peak rupture force, tensile strength, stiffness, modulus of elasticity, toughness, terminal velocity and drag coefficient) at three different moisture contents (14.40, 18.00 and 23.87%, w.b). Results showed that length, width, and thickness of the calyxes ranged from 41.10 - 53.10 mm, 20.60 – 24.1mm, and 1.11 – 1.32mm, respectively. Changes in bulk density was negligible as the calyx moisture content was increased from 14.4 to 23.87 % while increment with increased moisture content was recorded for values of surface area, true density, and porosity. The Peak rupture force, tensile strength, stiffness, modulus of elasticity and toughness of the calyxes ranged from 5.30 – 8.47 N; 442 – 692kNm^{-2}; 4.06 – 4.31kNm^{-1}; 13.47 - 14.78 MNm^{-2}, 0.0035 - 0.0112 J, respectively. Terminal velocity (TV) of the calyxes was between 2.78 – 3.22 ms^{-1} and the values for drag coefficient ranged from 1.60 x 10^{-3} – 2.9 x 10^{-3}.

Keywords: Aerodynamic properties, mechanical properties, physical properties, roselle calyxes

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INTRODUCTION

Research into agricultural and biological materials to identify properties and potential applications has been progressive. Much attention is particularly placed on those that find great industrial application and are economically viable. Hibiscus Sabdariffa L. (Malvaceae) (fig. 1), commonly known as hibiscus or roselle, grows in many tropical and sub-tropical countries and is one of highest volume specialty botanical products in international commerce (Plotto et al., 2004). It is an annual herbaceous shrub, growing to about three (3) meters in height, with red or green inflated calyxes (Babalola et al., 2001; Plotto et al., 2004; Qi et al., 2005). Different parts of the plant, have found variety of use in different fields. The leaves are used extensively for animal fodder and fiber (Dutt et al., 2009; Plotto et al., 2004). The works of (Akinoso and Suleiman, 2011; Ismail et al., 2008) reveals that the seed contain about 20% edible health promoting oils, which are rich in anti-oxidants.

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The calyxes of roselle are the part of commercial interest. Many literature have reported that the calyxes could be used for production of fruit drinks, juices, wines, jellies, jams, beverages, and ice-creams (Akinoso and Suleiman, 2011; Babalola et al., 2001; Juliani et al., 2009; Plotto et al., 2004). The extract of the calyxes has also been reported for its health benefits in several medical applications (Ali et al., 2005; Juliani et al., 2009). There has been an increasing demand for roselle calyxes over the last decade with about 15,000 metric tons entering international trade each year; however the quality of roselle from different countries are markedly different (Plotto et al., 2004). While the production of high quality hibiscus calyxes in developing countries is becoming an important for value addition and income generation activities for the benefit of rural communities (Juliani et al., 2009), most calyxes produced suffer severe mechanical damage during harvesting and post-processing resulting in significant revenue loss due to lack of compatible equipment and procedures for handling this crop. If the quality of calyxes required for international, regional and local markets are to be enhanced, there is the need for information on the mechanical and aerodynamic properties of this herbal product. Therefore, the objective of this study was to determine some physical, mechanical and aerodynamic properties of a dark red variety of roselle calyxes at three different moisture levels.

Figure 1. Typical dry roselle calyxes

MATERIALS AND METHODS

Material preparation

A dried, dark red variety of roselle calyxes was used for this study. The sample used was obtained from a local market in Ile-Ife, Osun State, Nigeria. The sample was divided into three equal portions by weight, 50g each. The initial moisture content (14.40% w.b.) of the calyxes was determined and then they were conditioned to three different moisture content levels

(14.40%, 18.00% and 23.87% w.b.) respectively by adding calculated amounts of distilled water, sealed hermetically and stored in a refrigerator 4 ± 1 °C for 24h prior to use.

Moisture content was determined by the method, AACC Method 44-15A (Moisture – Air-Oven Methods) (AACC, 2000; Akharume et al., 2016). 10g weighted sample of the calyxes were oven-dry at 105^{0}C for 24hrs. The moisture content (w.b) was calculated according to the equation.

$$MC = \frac{W_i - W_f}{W_i} \quad x\,100 \qquad (1)$$

Where W_i and W_f are initial and final moisture content respectively.

Physical properties

The physical properties determined for the roselle calyxes include dimensions, surface area, bulk and true densities, and porosity. The dimensions of the calyxes (fig. 2) was obtained by randomly selecting thirty (30) calyxes and measuring their length (from mid apex to the base of the calyx), breadth (the length of the base of the calyx) and thickness using a Vernier caliper and micro meter screw gauge (Mitutoyo, Japan) with accuracy of 0.001 mm. Surface area of the calyxes was determined according to (Nnebue et al., 2015). Calyxes were carefully spread and traced out on a graph paper and counting the number of squares. This method was used because of the irregular shape of the calyxes. The true density (ρ_t) of the roselle calyxes were determined by displacement method (Emadi and Saiedirad, 2011; Omobuwajo, Sanni, and Balami, 2000) using Toluene as liquid to avoid any possible absorption of moisture. The bulk density (ρ_b) was determined by using the mass/volume relationship (Omobuwajo et al., 2000). The porosity (ε) was calculated by the equation (Emadi and Saiedirad, 2011)

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t}\, x\,100 \qquad (2)$$

Where:

$\varepsilon =$ Porosity (dimensionless)
$\rho_t =$ True density (*g/cm^3*)
$\rho_t =$ True density (*g/cm^3*)

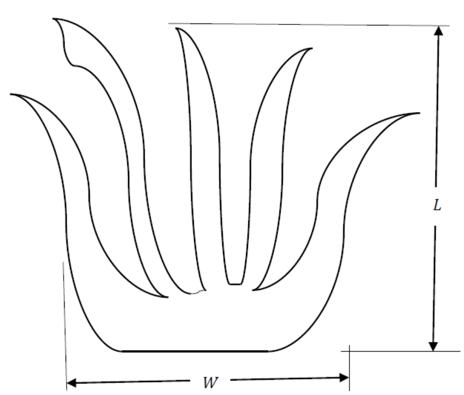

Figure 2. Schematic diagram of roselle calyx showing the axial dimension: L – length, W – width / breadth

Mechanical properties

An Instron universal testing machine (model 3369 UTM, M500 – 50KN, USA) was used to perform tensile tests on the calyxes. The instrument (Fig 3) consist of a fixed and adjustable clamps. Owning to the texture of the sample material, the loading speed was set as 2 mm/min for each of the tests. The calyxes were cut into rectangular strips and the dimension (thickness and width) were measured. The specimen was held longitudinally in the clamp and pulled axially automatically by the Instron machine until rupture. A computer data acquisition system recorded the magnitude of the applied load and the resulting elongation of the specimen. The test was replicated five (5) times for each sample and average obtained. A force – deformation curve was then generated from these data. The obtained data were used to determine the following tensile properties of roselle calyxes;

1. Rupture force (F_r) was taken as the maximum peak force required to rupture the calyx in accordance with (Singh and Reddy, 2006).
2. Tensile strength was calculated according to (Singh and Reddy, 2006) as

$$Tensile\ strength\ = \frac{\text{peak rupture force}}{\text{cross− sectional area (thickness x width) of the initial specimen.}} \quad (3)$$

3. Stiffness modulus (S) which is the slope of the force – deformation curve, in the apparent elastic region measured in kN/m (Koya et al., 2011).
4. Modulus of elasticity (E) was calculated as the slope of the initial linear portion of the stress and strain curve (Singh and Reddy, 2006).
5. Toughness which is the energy absorbed per unit volume. This was estimated by the area under the curve up to the rupture point (Koya et al., 2011)

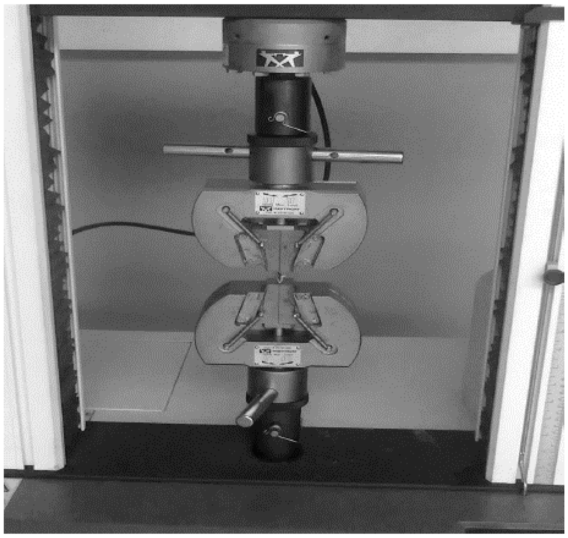

Figure 3. The Instron Universal Testing Machine (Model 3369) showing a rectangular strip of roselle calyx being pulled axially for determination of tensile properties

Aerodynamic properties

The terminal velocity of each part was experimentally measured using the floating method. A vertical air duct (Fig. 4) which was designed by the department of Agricultural and Environmental engineering, OAU, Ile – Ife was used for the test. The apparatus consists of a voltage regulator, an electric motor, a blower and a transparent wind tunnel. The method provides blowing air in a vertical duct for calyxes to be floated, the voltage was regulated intermittently to obtain the required air flux speed to suspend the calyx. The airflow velocity at time of suspension called terminal velocity (TV) was measured using a hot wire anemometer (Dwyer 471B-1, MA, USA) with an accuracy of 0.1% accuracy (Emadi, 2008; Emadi and Saiedirad, 2011). Five calyxes each were randomly selected from each of the moisture levels and used for the experiment with average values recorded for the various parameters determined.

The drag coefficient of the calyxes for each of the sample portion was calculated from the equation

$$C = \frac{2m_t\, g}{\rho_a\, (v_t)^2 A_t} \quad (4)$$

Where *C* is the drag coefficient, m_t is the mass of calyx in kg, v_t is terminal velocity experimentally measured in m/s, A_t is projected area of the calyx in m^2, *g* = gravitational acceleration in m/s^2, ρ_a is true density of air in kg/m^3.

While the projected area, A_t was calculated using the expression(Helmy, Derbala, Badr, and Shohyieb, 2009)

$$A_t = \frac{\pi}{4} LW \quad (5)$$

Where L is the length in meter and W is the width in meter.

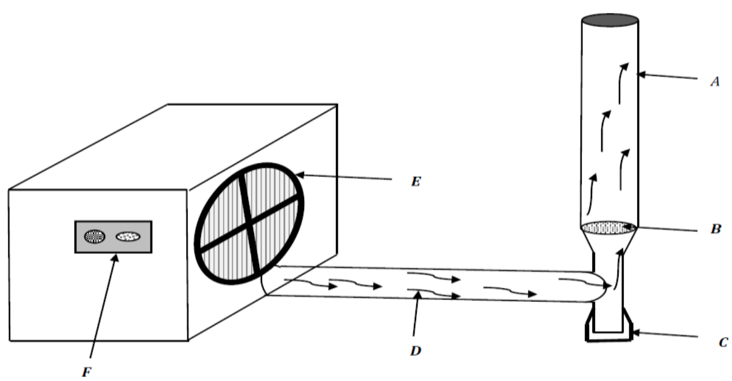

Figure 4. The Experimental set-up for determination of terminal velocity of the roselle calyxes: A – transparent wind tunnel; B – wire screen; C – base of the tunnel; D – air current; E – blower and F – voltage regulator

Experimental design and Statistical analysis

A completely randomized design was applied for the experiment in which there were three treatment samples (calyxes at moisture contents 14.40, 18.00 and 23.87%, w.b), thirty replications for dimensions (Length, width, thickness and surface area) and five replications for true density, bulk density, terminal velocity and the mechanical properties experiments. The analysis of variance (ANOVA) for the results was performed using the SAS Statistical Software 10.0 (StatSoft, 2012) (at 95% confidence interval).

RESULTS AND DISCUSSION

Physical Properties

The physical characteristic, dimensions, surface area, true density, bulk density and porosity of roselle calyxes are presented in Table 1. The values presented are within the ranges reported in literature for biological materials (Kaleta and Górnicki, 2011). Emadi and Saiedirad (2011) reported the principal dimension of saffron petals at 87.7% w.b. moisture content as 38.28 ± 3.28, 17.15±2.40 and 0.15±0.02 mm for length, width, and thickness respectively (Emadi and Saiedirad, 2011). The results from physical properties measurements show an increase in the thickness, true density and porosity with moisture content from 14.40 – 23.87% w.b. However, the difference in this properties with moisture content, is statistically significant at ($p < 0.05$). The increase could be as a result of rehydration of the cell wall of the calyxes which is accompanied by a higher change in mass relative to volume. This was confirmed by the works of (Chavoshgoli et al., 2014; Emadi and Saiedirad, 2011).

Table 1. Axial dimensions, surface area, true density, bulk density and porosity of roselle calyxes at different moisture contents.

Physical properties	Calyxes moisture content (% w.b)		
	14.40	18.00	23.87
Length (mm)	41.10 (3.7)	42.60 (4.40)	53.10 (4.40)
Width (mm)	20.60 (2.8)	21.60 (1.80)	24.10 (2.70)
Thickness (mm)	1.23 (0.13)	1.27 (0.11)	1.32 (0.12)
Surface Area (mm^2)	11.74 (1.70)	11.69 (2.30)	15.48 (0.93)
True density (g/cm^3)	0.74 (0.04)	0.75 (0.006)	0.83 (0.08)
Bulk density (g/cm^3)	0.11 (0.002)	0.11 (0.002)	0.11 (0.004)
Porosity (%)	85.14	85.64	86.42

Values in parentheses are standard deviation

Mechanical properties

The ranges of peak rupture force; tensile strength; stiffness; modulus of elasticity and toughness of roselle calyxes assayed at different moisture content are presented in Table 2. While Figure 5 presents the force-deformation curves of roselle calyxes under tensile loading at 2.00 mm/min at the three-moisture content (14.40, 18.00 and 23.87% w.b.). The values obtained for the calyx mechanical properties (peak rupture force, tensile strength, stiffness and toughness) increase with increasing moisture content, except for the modulus of elasticity. peak rupture force ranged from 5.30 – 8.47 N; tensile strength 442 – 692kNm^{-2}; stiffness 4.06 – 4.31kNm^{-1}; modulus of elasticity 13.47 - 14.78 $MNm^{-2}$and toughness 0.0035 - 0.0112 J. The increase in mechanical properties could be attributed to increase rigidity of the calyx cell wall from hydration by water molecules. Calyx cell wall like every other plant contains a lot of cellulosic material which upon absorption of water becomes more stable due to formation of hydrogen bonding with the water molecules, making it more tensile and less brittle. The decrease in the modulus of elasticity could be explained by the significant change in length of the sample due to an increase in rupture force. A similar trend was reported by (Singh and Reddy, 2006) who worked on the post-harvest physico - mechanical properties of orange peel. Their results show that the rupture force decrease from 15.60±2.5 – 10.80±2.5 N**,** tensile strength decreased from 0.173±0.031 – 0.125±0.03 Mpa and modulus of elasticity decreased from 1.57±0.54 – 1.11±0.19 Mpa for orange peels with initial moisture content of 292% db, stored in ambient condition for 1, 3, 7, and 10 days reaching a final moisture content of 252.8%.db. The difference in peak ruptures, tensile strength, stiffness, and modulus of elasticity, with moisture content except toughness were insignificant at (P >0.05).

Table 2. Peak rupture force; tensile strength; stiffness; modulus of elasticity and toughness of roselle calyxes at different moisture contents.

Mechanical properties	Calyxes moisture content (% w.b)		
	14.40	18.00	23.87
Peak rupture force F_r (N)	5.30 (1.16)	7.63 (0.7)	8.47 (1.48)
Tensile strength, σ (kNm^{-2})	442 (134.71)	605 (39.97)	692 (141.84)
Stiffness (kNm^{-1})	4.06 (0.46)	4.31 (1.08)	3.19 (1.14)
Modulus of elasticity, E (MNm^{-1})	14.78 (1.71)	13.47 (1.34)	3.81 (2.36)
Toughness (J)	0.0035 (0.0011)	0.0078 (0.0010)	0.0112 (0.0018)

Values in parentheses are standard deviation

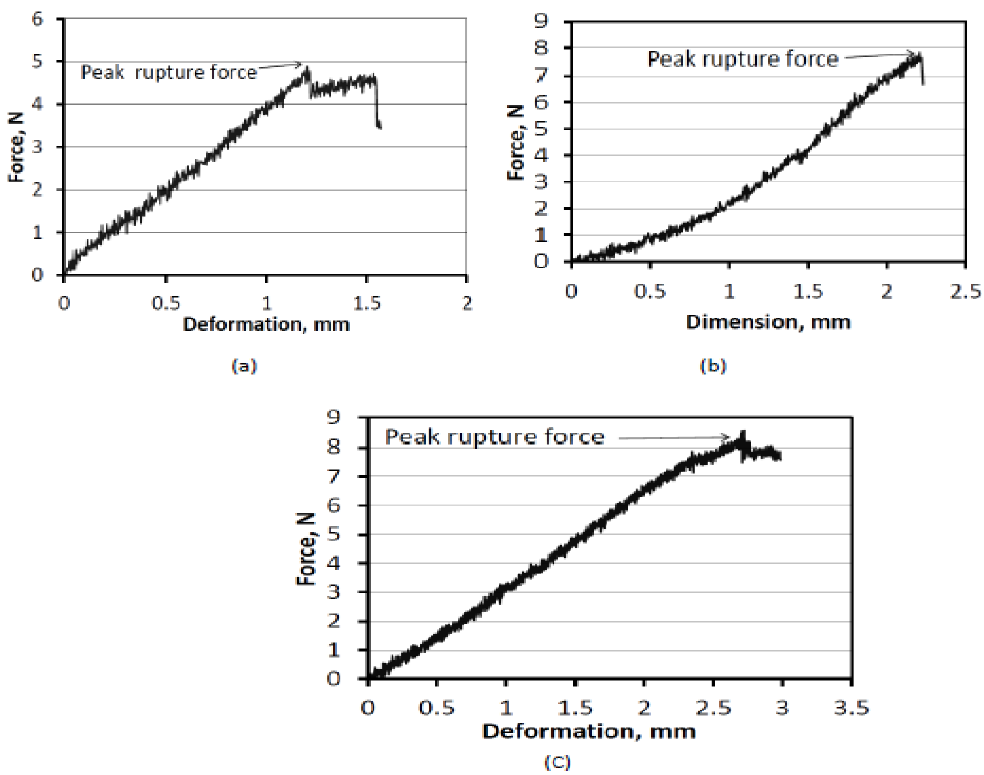

Figure 5. Average∗ Force-Deformation Curve of roselle calyxes under tensile loading at 2.00 mm/min at different moisture content (a) 14.40 % w.b (b) 18.00% w.b and (c) 23.87% w.b

Aerodynamic properties

Table 3 presents the average mass, terminal velocity and drag coefficient of roselle calyxes at different moisture contents. The calyxes exhibited aerodynamic instability during the experiments due to their asymmetrical and non-uniform shape. Results showed that the terminal velocity of calyxes ranges between 2.78 – 3.22 ms^{-1}, and the drag coefficient ranges from 1.60 x 10^{-3} – 2.9 x 10^{-3}, this is within the range reported for sunflower petals and other similar materials (Emadi and Saiedirad, 2011). Although the result did not show a linear increase in terminal velocity as moisture content increases, the drag coefficient decreases with increasing moisture content. The variation could be due to inconsistencies in mass and surface area of sampled calyxes.

Table 3. Average mass, terminal velocity and drag coefficient of roselle calyxes at different moisture content

Aerodynamic properties	Calyxes moisture content (% w.b)		
	14.40	18.00	23.87
Average mass (kg)	0.56 (0.047)	0.62 (0.050)	0.64 (0.054)
Terminal velocity (ms^{-1})	2.78 (0.27)	3.22 (0.43)	3.07 (0.36)
Drag coefficient	0.0029	0.0022	0.0016

Values in parentheses are standard deviation

CONCLUSION

The physical, mechanical and aerodynamic properties of roselle calyxes determined in relation to different moisture contents shows that most of the parameters measured increases significantly with moisture content, with the exception of the length, width, bulk density, modulus of elasticity and drag coefficient. The results provide preliminary data that will find application in the design of harvesting and post-processing handling equipment and techniques (e.g. separators, cleaners) for processing and handling roselle calyxes.

REFERENCES

AACC, I. 2000. Approved Methods of the AACC. Association of Cereal Chemists, St. Paul.

Akharume, F. U., Singh, K., and Sivanandan, L. 2016. Characteristics of apple juice and sugar infused fresh and frozen blueberries. LWT-Food Science and Technology, 73, 448-457.

Akinoso, R., and Suleiman, A. 2011. Heat treatment effects on extraction of roselle (Hibiscus sabdariffa L) seed oil. European Journal of Lipid Science and Technology, 113(12), 1527-1532.

Ali, B. H., Wabel, N. A., and Blunden, G. 2005). Phytochemical, pharmacological and toxicological aspects of Hibiscus sabdariffa L.: a review. Phytotherapy Research, 19(5), 369-375.

Babalola, S., Babalola, A., and Aworh, O. 2001. Compositional attributes of the calyces of roselle (Hibiscus sabdariffa L.). The Journal of Food Technology in Africa, 6(4): 133-134.

Chavoshgoli, E., Abdollahpour, S., Abdi, R., and Babaie, A. 2014. Aerodynamic and some physical properties of sunflower seeds as affected by moisture content. Agric Eng Int: CIGR Journal, 16(2), 136-142.

Dutt, D., Upadhyay, J., Singh, B., and Tyagi, C. 2009. Studies on Hibiscus cannabinus and Hibiscus sabdariffa as an alternative pulp blend for softwood: An optimization of kraft delignification process. Industrial crops and products, 29(1), 16-26.

Emadi, B. 2008. Design of a wind tunnel for separating flower parts of saffron. Paper presented at the 9th Global Congress on Manufacturing and Management-GCMM2008.

Emadi, B., and Saiedirad, M. 2011. Moisture-dependent physical properties of saffron flower. Journal of Agricultural Science and Technology, 13, 387-398.

Helmy, M., Derbala, A., Badr, S., and Shohyieb, S. 2009. Effect of physical and engineering properties of some corn seeds varieties on pneumatic machine performance. Misr Journal of Agricultural Engineering, 26(3), 1397-1411.

Ismail, A., Ikram, E. H. K., and Nazri, H. S. M. 2008. Roselle (Hibiscus sabdariffa L.) seeds-nutritional composition, protein quality and health benefits. Food, 2(1), 1-16.

Juliani, H. R., Welch, C. R., Wu, Q., Diouf, B., Malainy, D., and Simon, J. E. 2009. Chemistry and Quality of Hibiscus (Hibiscus sabdariffa) for Developing the Natural-Product Industry in Senegal. Journal of Food Science, 74(2).

Kaleta, A., and Górnicki, K. 2011. Databases on physical properties of plants and agricultural products Encyclopedia of Agrophysics (pp. 189-194): Springer.

Koya, O., Ogunsina, B., and Opeyemi, O. 2011. Deformation and dehulling of sponge gourd (Luffa aegyptiaca) seeds. International Journal of Food Properties, 14(2), 432-440.

Nnebue, O., Ogoke, I., and Obilo, O. 2015. Leaf area determination in Roselle (Hibiscus sabdariffa L.) using linear measurements. Inernational Journal of Science, Environment and Technology, 4(2), 407-413.

Omobuwajo, T., Sanni, L., and Balami, Y. 2000. Physical properties of sorrel (Hibiscus sabdariffa) seeds. Journal of Food Engineering, 45(1), 37-41.

Plotto, A., Mazaud, F., Röttger, A., and Steffel, K. 2004. Hibiscus: Post-production management for improved market access organisation: Food and Agriculture Organization of the United Nations (FAO): AGST.

Qi, Y., Chin, K. L., Malekian, F., Berhane, M., and Gager, J. 2005. Biological characteristics, nutritional and medicinal value of roselle, Hibiscus sabdariffa. Circular-Urban Forestry Natural Resources and Environment, 604, 1-2.

Singh, K. K., and Reddy, B. S. 2006. Post-harvest physico-mechanical properties of orange peel and fruit. Journal of Food Engineering, 73(2), 112-120.

StatSoft, S. (2012). 11: 2012: Copyright© StatSoft.