Effects of pre-mature harvest and heat exposure on physical and mechanical properties of *Pandanus tectorius* leaves

John A Toman Corresp. [1]

[1] Integrative Biology, University of California, Berkeley, Berkeley, United States

Corresponding Author: John A Toman
Email address: jtoman@berkeley.edu

Plant materials have long been utilized for human use because of their wide range of physical properties and incredible mechanical efficiency as eco-friendly structures. One example of their use today is the practice of using the sturdy leaves of *Pandanus tectorius* for thatching purposes. An increase in modern demand for *P. tectorius* is pressuring farmers to deviate from traditional harvesting methods in an attempt to increase leaf yield. With little knowledge of the repercussions of their new practice, modern farmers are pre-maturely harvesting leaves through heat-induced leaf drying while the leaves remain on the tree. In this study, life-history characteristics, physical and mechanical properties of *P. tectorius* leaves on Mo’orea, French Polynesia are examined to determine whether or not this deviation from traditional harvest methods reduces leaf efficacy as a thatching material. Quantitative measures of *P. tectorius* leaves suggest that pre-mature harvest does not alter the size of collected leaves for thatch because most leaves on a tree have already reached maximum growth. Heat-induced leaf drying, however, reduces the tensile strength of *P. tectorius* leaves by about 25%. Further research may find that this loss in leaf tensile strength may correlate to less robust roofing structures, hindered longevity and ultimately an increase in energy cost to repair and rebuild such structures.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2732v1 | CC BY 4.0 Open Access | rec: 18 Jan 2017, publ: 18 Jan 2017

Effects of pre-mature harvest and heat exposure on physical and mechanical properties of *Pandanus tectorius* leaves

John Albert Toman
Integrative Biology, University of California, Berkeley, U.S.A.

Corresponding Author:
John Toman
13954 Orange Blossom Rd, Oakdale, California, 95361, United States of America
Email address: jtoman@berkeley.edu

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2732v1 | CC BY 4.0 Open Access | rec: 18 Jan 2017, publ: 18 Jan 2017

Abstract

Plant materials have long been utilized for human use because of their wide range of physical properties and incredible mechanical efficiency as eco-friendly structures. One example of their use today is the practice of using the sturdy leaves of *Pandanus tectorius* for thatching purposes. An increase in modern demand for *P. tectorius* is pressuring farmers to deviate from traditional harvesting methods in an attempt to increase leaf yield. With little knowledge of the repercussions of their new practice, modern farmers are pre-maturely harvesting leaves through heat-induced leaf drying while the leaves remain on the tree. In this study, life-history characteristics, physical and mechanical properties of *P. tectorius* leaves on Mo'orea, French Polynesia are examined to determine whether or not this deviation from traditional harvest methods reduces leaf efficacy as a thatching material. Quantitative measures of *P. tectorius* leaves suggest that pre-mature harvest does not alter the size of collected leaves for thatch because most leaves on a tree have already reached maximum growth. Heat-induced leaf drying, however, reduces the tensile strength of *P. tectorius* leaves by about 25%. Further research may find that this loss in leaf tensile strength may correlate to less robust roofing structures, hindered longevity and ultimately an increase in energy cost to repair and rebuild such structures.

Introduction

Human beings of all cultures and ancestry have developed a profoundly important ethnobotanical relationship with plants. Evidence suggests this human-plant relationship began in the New World Tropics about 4,000 to 11,000 years ago when indigenous neotropical people began cultivating and domesticating a seemingly inexhaustible source of plant materials (Piperno 2011). For example, Pacific Islanders have long thatched their roofs with Pili Grass and Palm Fronds, wove their sandals out of banana leaves and reached Tahiti, French Polynesia in Canoes made of planks (Krauss 1974). Utilization of local plant materials for construction has many advantages over modern approaches to development. Such advantages include a reduced energy cost for its transport and reduced environmental impact because the material eventually degrades (Barreca 2012). As research uncovers life history characteristics, morphologies, and properties of ethnobotanical plant materials, agriculturalists, farmers, and engineers are informed how to better utilize, harvest and manage materials in order to maximize quality and efficiency. Consequently, humans benefit from these advancements, especially in areas where people rely on ethnobotany for their well-being.

Pacific Island culture and tradition has long used *Pandanus tectorius* (Pandandanales), a monocotyledon native to Polynesia, for its nutritious edible fruits, poles and branches for construction, and even the leaves for weaving, garlands, and thatching (Thompson 2006; Gallaher *et al.* 2015). On the island of Mo'orea, French Polynesia, the practice of using *P. tectorius* leaves for thatching purposes is still a popular practice for many citizens (T.H. Murphy, pers. comm.). However, acquiring a sufficient supply of *P. tectorius* leaves often proves an expensive and time consuming task. At present, Mo'orean citizens are required to make the 87 km long boat journey from Mo'orea to the island Mai'ao where wild *P. tectorius* produces substantial leaf yields. Traditionally, only leaves that died and fell naturally from the tree were deemed worthy to be used for thatching (T.H. Murphy, pers. comm.). Recently, however, residents have become so opposed to making the trek from Mo'orea to Mai'ao that they have begun manipulating the natural rate by which leaves fall from the tree. They set fires underneath the branches of living trees in order to dry out the leaves more quickly; this causes them to die and drop off sooner than they originally would have (T.H. Murphy, pers. comm.). Skeptical locals have coined this method the “cheaters harvest”. It is not known whether or not this non-traditional harvest method affects the leaves efficacy as a thatching material. This paper aims to reveal the deleterious effects of the “cheater’s harvest” by investigating if pre-mature leaf death via fire results in leaves that are smaller, thinner and weaker when compared to leaves harvested via traditional methods.

Materials & Methods

Study site and species

This study was conducted on the island of Mo’orea in French Polynesia through the months of September and November 2016. Mo’orea is a small (134 km^2) island created through volcanism 1.5 – 2.5 mya. *Pandanus tectorius* (Pandanaceae) leaves were collected from four mature plants between the ages of 15 and 30 years, as estimated by the methods proposed by Ash (1987). These trees were evenly distributed between two different study sites; one site was across the street from the Atitia Center on the coast of Cook’s Bay (17°29'34.41"S 149°49'34.91"W) and the other was located on a hillside in the village of Atiha on the southern tip of the island (17°35'26.32"S 149°50'20.07"W).

Experimental design

This study tested two working hypothesis through two different experiments: (1) tracing leaf life-history morphology and (2) effect of heat treatment on tensile strength. All leaves were randomly collected from branch diameters between 4-7 cm. Leaf size in this study ranged from 1-3 m at maturity. All experiments were performed within 24 hours of collection to avoid differences associated with drying between sampling.

Tracing leaf life-history morphology

Pandanus tectorius leaf growth occurs in a highly organized and spirally-arranged fashion at branch apices. Since each branch contains a single apical meristem, leaves are born one at a time at the tip of the branch. Consequently, the innermost leaves of a branch are the youngest and relative age increases as one moves away from the branch apex. This distinctive growth pattern of *P. tectorius* allows one to measure and track growth as a function of relative age by taking various leaf morphology measurements and noting the particular order of leaves as they are removed. All leaves from three different branches were collected by removing the oldest, outermost leaves first and working towards the branch apex and meristem. Leaves were removed one at a time and numbered in the particular order by which they were removed in order to keep precise relative age estimates intact. Leaf length was measured to the nearest tenth of a centimeter using a transect measuring tape, width to the nearest millimeter using a ruler, and thickness to the nearest hundredth of a millimeter using a Mitutoyo Digimatic Caliper. Simple linear regression analyses were applied on a scatterplot of leaf length, width, and thickness as a function of number of leaves from the apical meristem by using R (R Core Development Team, 2013) to investigate plant life-history correlates and growth patterns.

Effect of heat treatment on tensile strength

This experiment investigated the effects of exposure of *P. tectorius* leaves to heat on their tensile strength. This was tested by collecting about 50 mature green leaves from two trees at the collection site across the street from the Atitia Center. Leaves were carefully selected to include only symmetrical and undamaged leaves. To control for inter-leaf variance, leaves were split down the midrib producing 50 pairs of nearly identical leaf strips. One leaf strip of each pair was randomly assigned to either the heat treatment or traditional method of sun-drying. Heat-treated strips were placed in a conventional propane oven set to “broil” at 90 °C. To avoid burning the leaves, they were removed after one hour of treatment and set out to air-dry the fractional remainder of water content still apparently remaining. Leaves selected for sun-drying were placed outside in broad daylight with a fan to supply a constant breeze. To prevent leaf curling during the drying process, leaves of both treatments were weaved through an oven rack. Once leaves were dry, tensile strengths were measured via the pulling force required to break leaf strips. This was achieved by placing weights seven inches apart on each end of the leaf strips. A luggage scale with a flat hook was placed directly in the middle of these weights. The upwards pulling force required to break the leaf strips was recorded in kilograms. A paired t-test was performed to analyze the difference in mean leaf tensile strength between drying methods using R (R Core Development Team, 2013).

Results

Tracing leaf life-history morphology

Leaf thickness increased linearly from 0.17 mm to 1.24 mm with little variance across all branches (Linear regression analysis, p-value < 0.001, df = 37, $R^2 = 0.94$) until the 16th leaf from the meristem was reached. However, beyond the 16th leaf the correlation appeared to cease completely (Linear regression analysis, p-value > 0.1, df = 67 $R^2 = 0.016$). The average leaf thickness of all branches sampled beyond the 16th leaf was 1.29 mm. A total of 106 leaves were measured for thickness (*Figure 1)*. The same general outcome for leaf length and width was observed, although max length and width differed between branches. The first 10 leaves from the meristem on each branch increased linearly in width from about 2.59 to 76.0mm (Linear regression analysis, p-value < 0.001, df = 25, $R^2 = 0.88$). Although max width ranged from 64 to 88 mm between branches, the correlation was lost completely on all branches sampled for width beyond about the 10th leaf from the meristem. A total of 102 leaves were measured for width (*Figure 2*). The first 14 leaves from the meristem on all branches also increased linearly in length from 11.4 to 217.0 cm (Linear regression analysis, p-value < 0.001, df = 33, $R^2 = 0.88$). Beyond the 14th leaf the correlation between length and number of leaves from the meristem again disappeared (*Figure 3*). Of the 110 leaf length measurements that were recorded, 18 leaf length measurements were omitted due to a fruiting event that had occurred on one of the branches. The fruiting body was observed between the 36th and 35th leaf from the meristem. The length of the 36th leaf was 183.4 cm and the length of the 35th leaf decreased drastically to 23.3 cm. These two leaves were separated only by the remnants of a fruiting body. Length measurements of leaves further from the fruiting body increased linearly until the average maximum height of about 226.4 cm was reached once again (*Figure 4*). All aspects of leaf morphology are related in a positive and linear manner. Leaf length and width were the most closely correlated variables (Linear regression analysis, p-value < 0.001, df = 92, $R^2 = 0.93$, slope = 0.37) (*Figure 5)*. Thickness is also correlated with length (Linear regression analysis, p-value < 0.001, df = 92, $R^2 = 0.68$, slope = 0.005mm) (*Figure 6)* and width (Linear regression analysis, p-value < 0.001, df = 102, $R^2 = 0.7$, slope = 0.013mm) (*Figure 7)*.

Leaf tensile strength and drying method

The tensile strength of sun-dried leaves ranged from 4.4 to 20.6 kilograms; where-as, heat-dried leaf tensile strength ranged from 3.8 to 16.3 kilograms (*Figure 8*). The mean tensile strength of sun-dried leaves was approximately 11.2 kilograms, but only about 8.4 kilograms for heat-dried leaves, a difference of about 2.8 kilograms (*Figure 8*). The mean tensile strength of sun-dried leaves was greater than heat-dried leaves (Paired t-test, t = 5.18, df = 51, p-value < 0.001).

Discussion

This study began by investigating the effects of pre-mature leaf harvest on leaf size. Leaf life-history morphology measurements provided evidence that the youngest leaves on any given branch grow quickly and at a nearly identical rate in thickness, width and length (*Figures 1, 2 & 3*). This growth is abruptly halted when leaves reach their maximum size at maturity. Maximum leaf width and length varied by branch because leaf size depends on stem diameter ('Corner's Rule, Hall *et al.* 1978). Leaf thickness, however, varied very little by the branches sampled in this study. The point at which leaves stopped growing also varied by branch. In all cases, the outermost leaves on the tree were fully mature, showed no evidence of continued growth and constituted more than half of the total number of leaves on the branch. This implies that leaves do not grow continuously throughout the entire duration of their life and that the outermost leaves on any given branch are roughly the same size.

The "cheater's harvest" has earned a poor reputation with locals for the non-traditional pre-mature harvesting of leaves via fire. However, inner leaves and meristems are so well protected by the outermost leaves that they are able to survive moderate fire (Ash 1987). In other words, only the outermost leaves of branches are scorched and collected during the "cheater's harvest." Considering that the outermost leaves on any given branch were found to all roughly be the same size, it is unlikely that pre-mature leaf harvest would result in smaller leaves. However, the long term-effects of this practice may be a greater threat. For example, photosynthesis is vital for growth and survival of virtually all plants (Lambers 2008). The "cheater's harvest" is robbing *P. tectorius* of photosynthetically viable organelles through the pre-mature harvesting of living leaves. The long-term effects of such organelle loss on the health of *P. tectorius* individuals should be examined as it may lead to the long-term decline of average leaf size as the plant becomes progressively less photosynthetically viable. Nonetheless, no evidence of any immediate decrease in leaf size due to pre-mature harvesting was observed. If there is an unforeseen deleterious outcome associated with this method that is leading to the decreased longevity of roofs as observed by locals, something else must be causing it.

In an attempt to quantify any immediate and negative impacts on *P. tectorius* leaf tensile strength that could be attributed to the "cheaters harvest", a closer look at the physical factors associated with fires used during this method were investigated. This investigation suggested that even a modest and short term exposure to heat negatively impacts the tensile strength of *P. tectorius* leaves by about 2.8 kilograms of pulling force (*Figure 8*). This accounts for nearly a 25% decrease in leaf tensile strength. The geometry of a deformed cell wall is a major determinant of its tensile strength (Gibson 2012). It is therefore possible that exposure of *P. tectorius* leaves to heat is inducing deformation of the cell wall within the heat-treated leaves that is not occurring in the sun-dried leaves. Further microscopy analysis may find an increased number of cell wall abnormalities among heat-treated leaves providing a potential mechanism to explain their reduced tensile strength.

The quality of the thatching material used for construction is a good estimation of the quality of the roof as a whole (Barreca 2012). With evidence to suggest the "cheater's harvest" produces weaker leaves, roofs made with this thatching material will likely sacrifice structural integrity and longevity when compared to traditionally thatched roofs. A long-term study of roofs made with leaves collected from each of these harvest methods is recommended to quantify this difference. Nonetheless, this decrease in overall strength as a roofing structure may be the reason behind the decreased roof longevity observed by locals.

Conclusion

The short term effects of pre-mature *Pandanus tectorius* leaf harvest on leaf morphology is virtually undetectable because most leaves on a tree have already stopped growing. Modest and short application of heat upon leaves, however, has deleterious effects on their tensile strength. Traditional *P. tectorius* leaf harvest methods produce thatching material that is stronger than more modern approaches because the leaves are never exposed to heat. It should therefore be recommended that *P. tectorius* farmers physically remove the outermost leaves of each branch and lay the leaves out to dry in the sun, rather than using fire. It is imperative we practice the correct utilization of the most suitable natural building materials because it will increase the time before roof repair and replacement are required. A renewed interest in bioconstruction materials and techniques can prove to be a prudent starting place for the search for eco-friendly technical solutions or the advancement of modern engineering. This will ultimately lead to less energy cost for the transport of new building materials and reduce environmental impacts by reducing addition of materials to the waste stream. These results demonstrate the need for further research when deviating from methods practiced by traditional ethnobotanists because their methods have worked and been trusted for centuries, lending to their apparent wealth of knowledge in the subject.

References

Ash J. “Demography Dispersal and Production of *Pandanus tectorius,* Pandanaceae, in Fiji.” Australian Journal of Botany. 1987;35(3):313-330. Accessed Sep 30, 2016. doi: 10.1071/BT9870313.

Barreca, Francesco. "Use of Giant Reed *Arundo donax* L. in Rural Constructions." *Agricultural Engineering International: CIGR Journal* 14.3 (2012): 46-52.

Gallaher T, Callmander MW, Buerki S, Keeley SC. A long distance dispersal hypothesis for the pandanaceae and the origins of the pandanus tectorius complex. Mol Phylogenet Evol. 2015;83:20-32. Accessed Oct 3, 2016. doi: 10.1016/j.ympev.2014.11.002.

Gibson, Lorna J. "The Hierarchical Structure and Mechanics of Plant Materials." *Journal of the Royal Society Interface* 9.76 (2012): 2749-2766.

Hall C, F., Oldeman, R. A. A., and Tomlinson, P. R. (1978). 'Tropical Trees and Forests.' (Springer- Verlag: New York.)

Krauss, Beatrice H. "Ethnobotany of the Hawaiians." (1974): 1-29. Web. 17 Oct. 2016.

Lambers, Hans, F. Stuart Chapin III, and Thijs L. Pons. "Photosynthesis." *Plant physiological ecology*. Springer New York, 2008. 11-99.

Murphy, H. Personal communication regarding *Pandanus* spp. ethnoecology on Mo'orea, French Polynesia; 2016.

Piperno, Dolores R. "The origins of plant cultivation and domestication in the New World tropics." *Current Anthropology* 52.S4 (2011): S453-S470.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Thomson, Lex AJ, et al. "Pandanus tectorius (pandanus)." *Species profiles for Pacific island agroforestry. Permanent Agriculture Resources (PAR)* (2006).

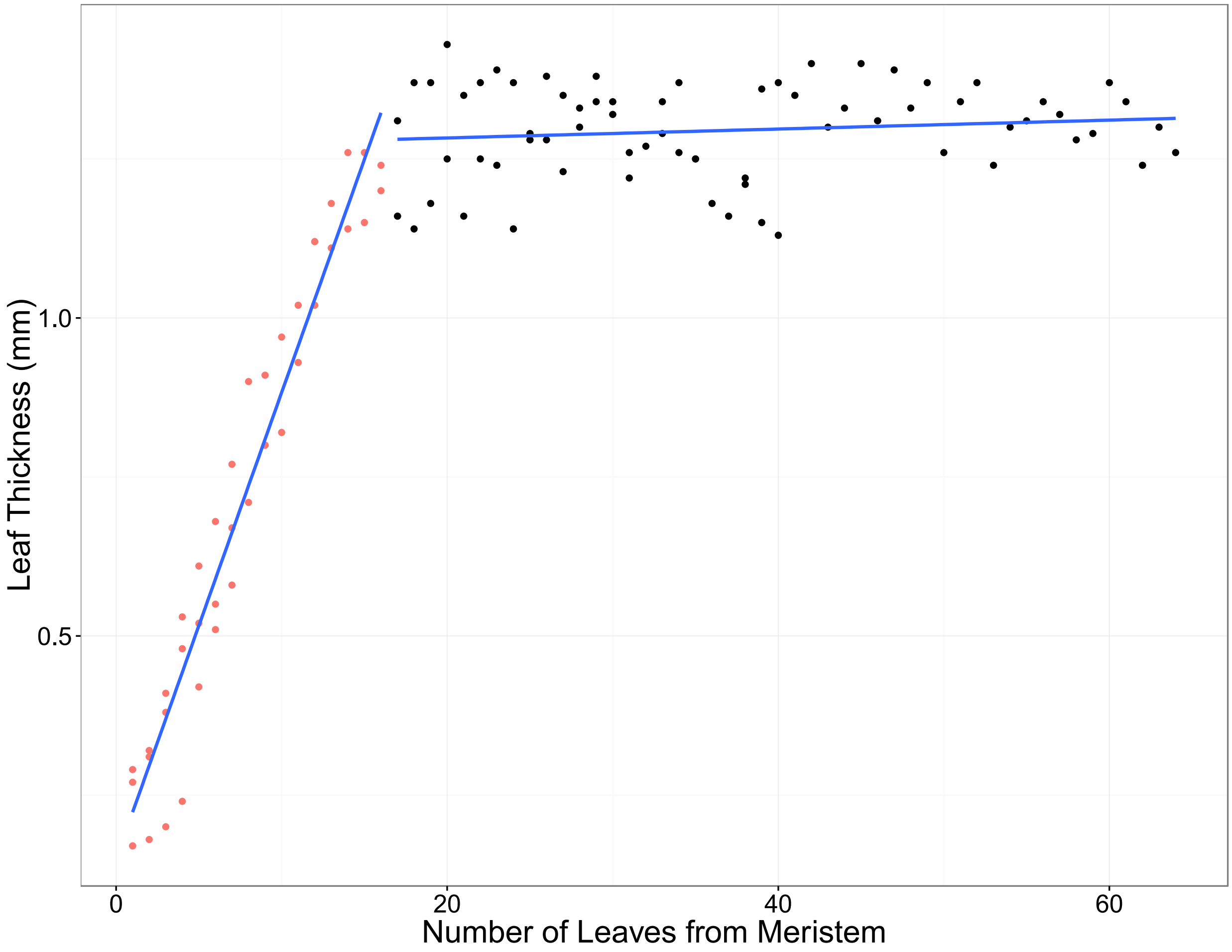

Figure 1. Scatterplot of leaf thickness (y-axis, mm) versus relative leaf age (x-axis), as measured by the number of leaves from the meristem in *Pandanus tectorius*. The red data points represent the first 16 leaves from the meristem on three different branches; where-as, black data points represent leaves found at least 16 leaves from the meristem. The blue lines represent the line of best fit for their respective datasets. The rightmost blue line represents best fit for the 16 youngest leaves of the branches sampled ((Linear regression analysis, $p < 0.001$, df = 37, $R^2 = 0.94$). The leftmost blue line represents the best fit for those leaves beyond the 16th (Linear regression analysis, p-value > 0.1, df = 67 $R^2 = 0.016$). The grey clouds surrounding these lines represents their respective 95% confidence intervals.

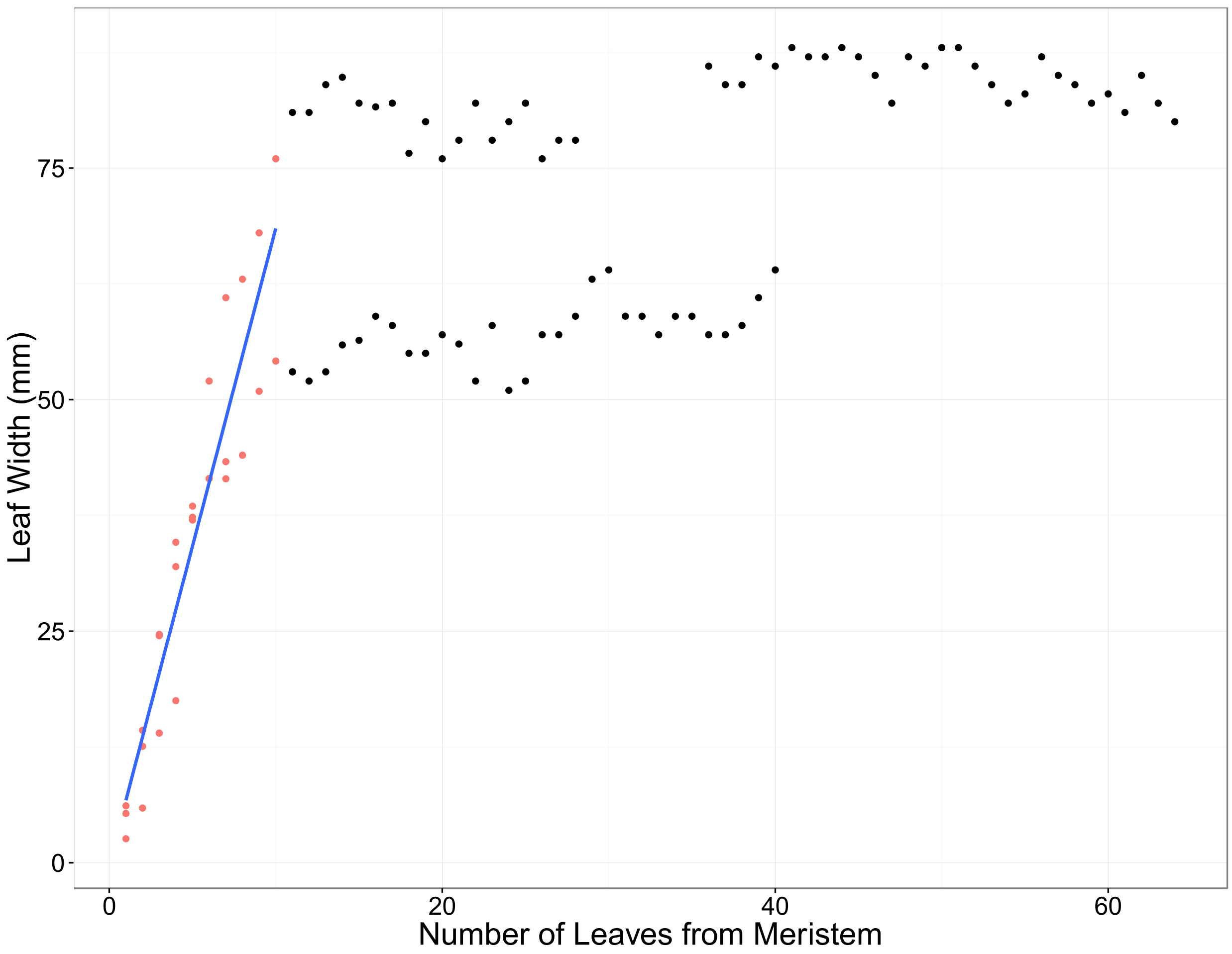

Figure 2. Scatterplot of leaf width (y-axis, mm) versus relative leaf age (x-axis), as measured by the number of leaves from the meristem in *Pandanus tectorius*. The red data points represent the first 10 leaves from the meristem on three different branches; where-as, black data points represent leaves found at least 10 leaves from the meristem. The blue line represents the line of best fit for the 10 youngest leaves of the three branches sampled ((Linear regression analysis, $p < 0.001$, $df = 25$, $R^2 \approx 0.88$). The grey cloud surrounding this line represents the 95% confidence interval for the line of best fit.

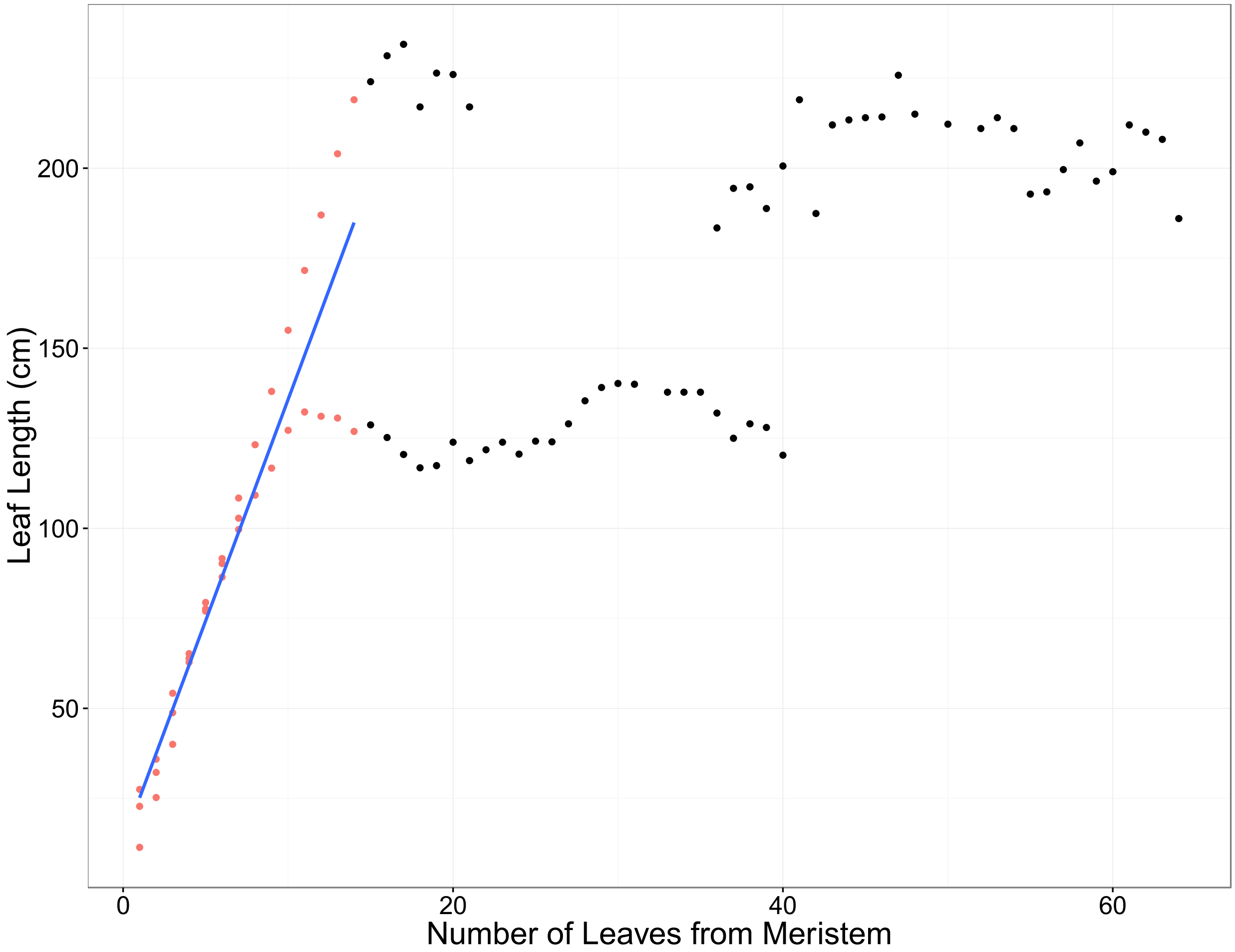

Figure 3. Scatterplot of leaf length (y-axis, cm) versus relative leaf age (x-axis), as measured by the number of leaves from the meristem in *Pandanus tectorius*. The red data points represent the first 14 leaves from the meristem on three different branches; where-as, black data points represent leaves found at least 14 leaves from the meristem. The blue line represents the line of best fit for the 14 youngest leaves of the three branches sampled ((Linear regression analysis, $p < 0.001$, $df = 33$, $R^2 \approx 0.88$). The grey cloud surrounding this line represents the 95% confidence interval for the line of best fit.

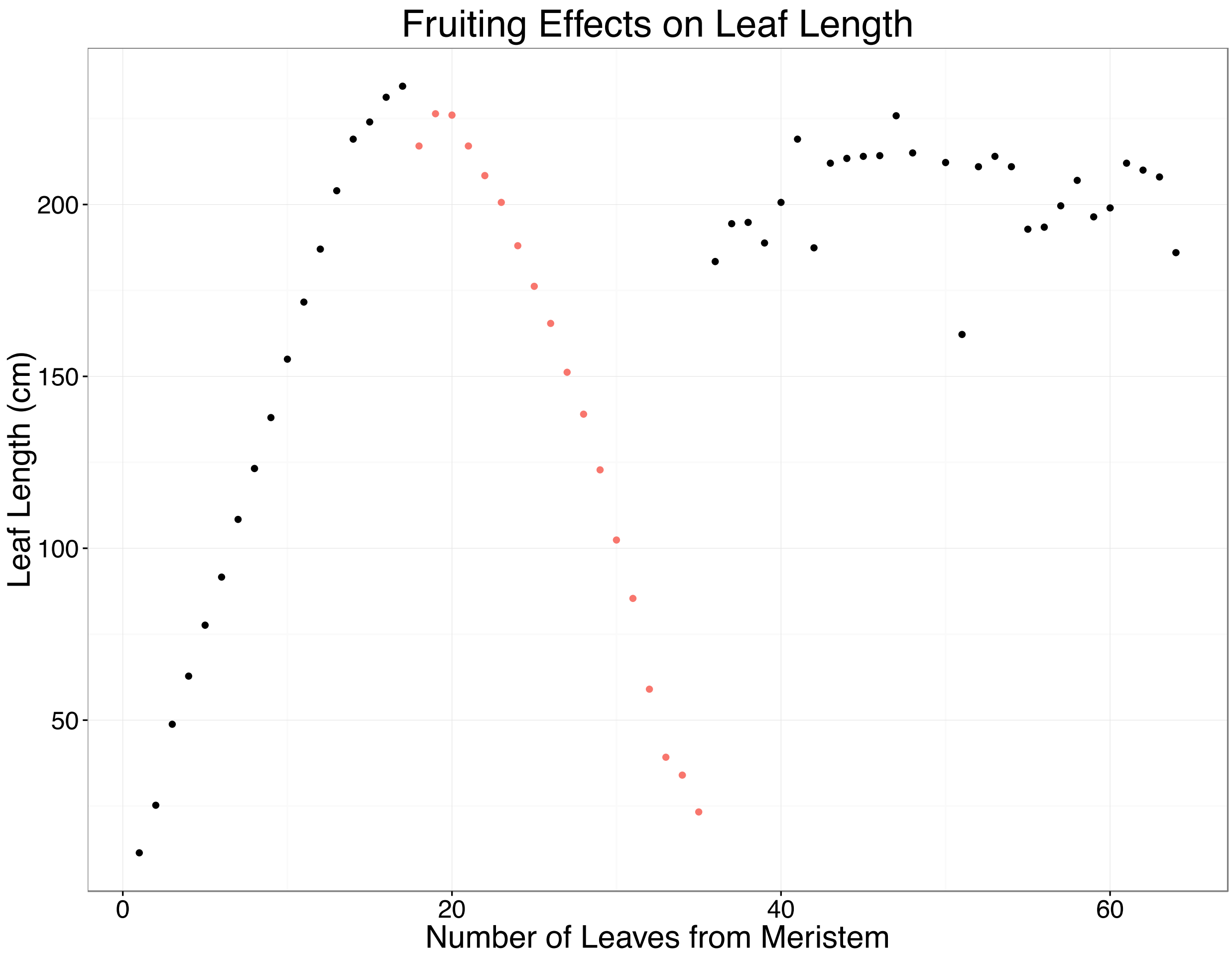

Figure 4. Scatterplot of leaf length (y-axis, cm) versus relative leaf age (x-axis), as measured by the number of leaves from the meristem in *Pandanus tectorius*. All of the data points on this graph represent leaf lengths acquired from one fruiting tree branch. The red data points represent the leaves affected by the fruiting event, which consisted of leaves 18 – 35. The fruiting body was located between leaves 35 & 36. Leaf length dropped immediately upon commensal of the fruiting event and gradually increased as the fruit grew.

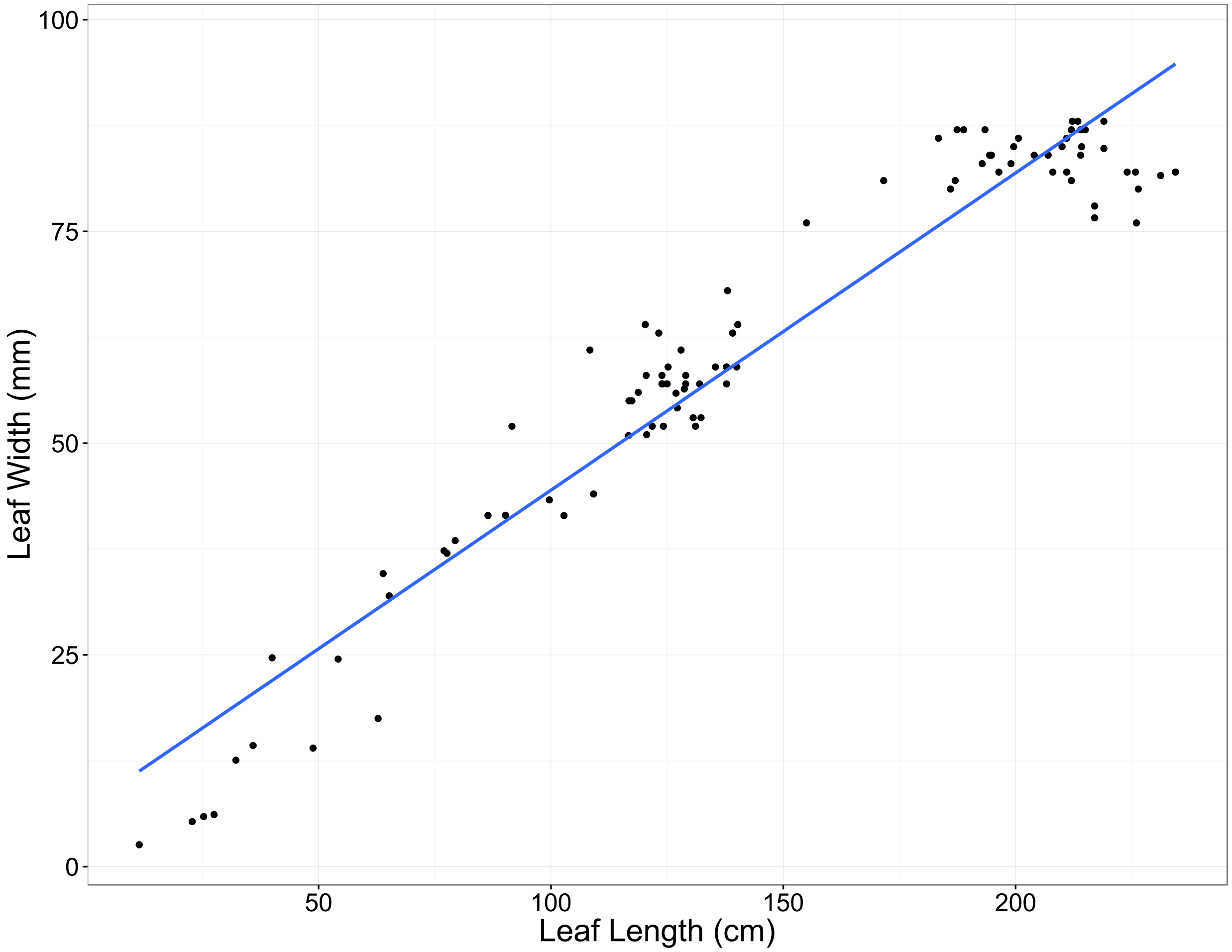

Figure 5. Scatterplot showing the relationship between *P. tectorius* leaf width and length. The two variables are related in a linear manner where approximately each increase of 1 cm in leaf length is associated with an increase of 0.37 mm in width, as represented by the blue line of best fit and its respective 95% confidence interval. (Linear Regression Analysis, p-value < 0.001, df = 92, $R^2 = 0.93$, slope = 0.37)

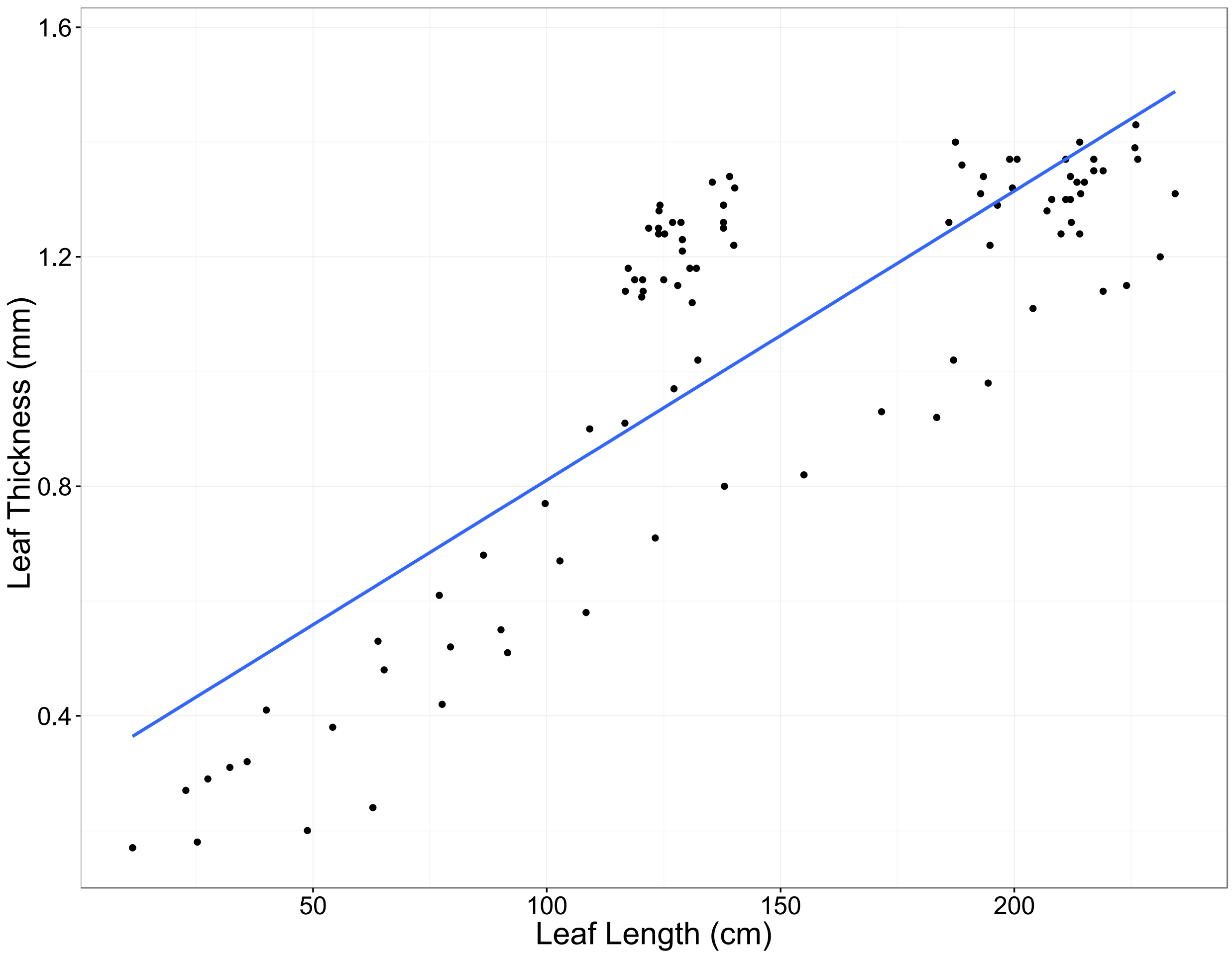

Figure 6. Scatterplot showing the relationship between *P. tectorius* leaf thickness and length. The two variables are related in a linear manner where approximately each increase of 1 cm in leaf length is associated with an increase of 0.005 mm in length, as represented by the blue line of best fit and its respective 95% confidence interval. (Linear regression analysis, p-value < 0.001, df = 92, R^2 = 0.68, slope = 0.005mm).

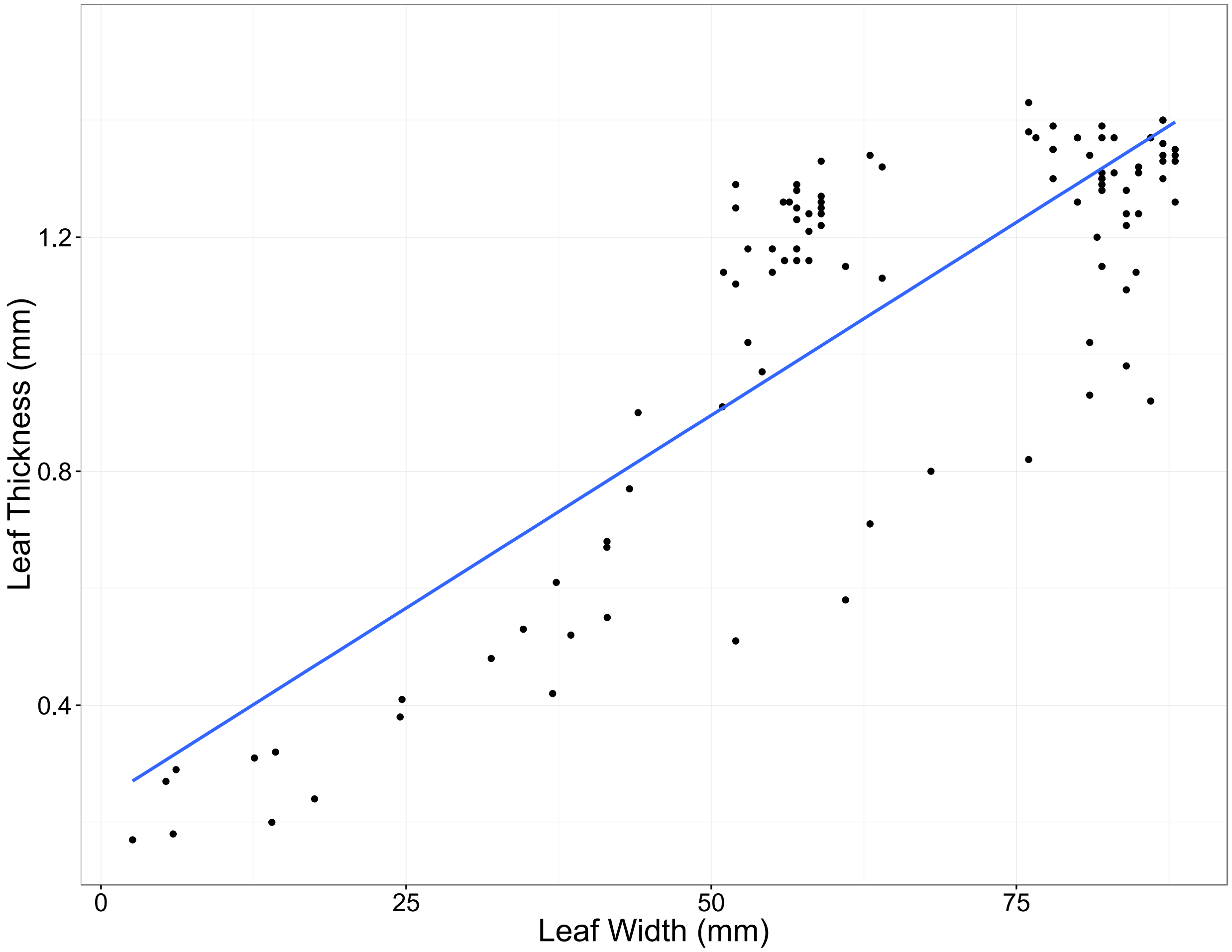

Figure 7. Scatterplot showing the relationship between *P. tectorius* leaf thickness and width. The two variables are related in a linear manner where approximately each increase of 1 mm in leaf width is associated with an increase of 0.013 mm in thickness as represented by the blue line of best fit and its respective 95% confidence interval. (Linear regression analysis, p-value < 0.001, df = 102, $R^2 = 0.7$, slope = 0.013mm)

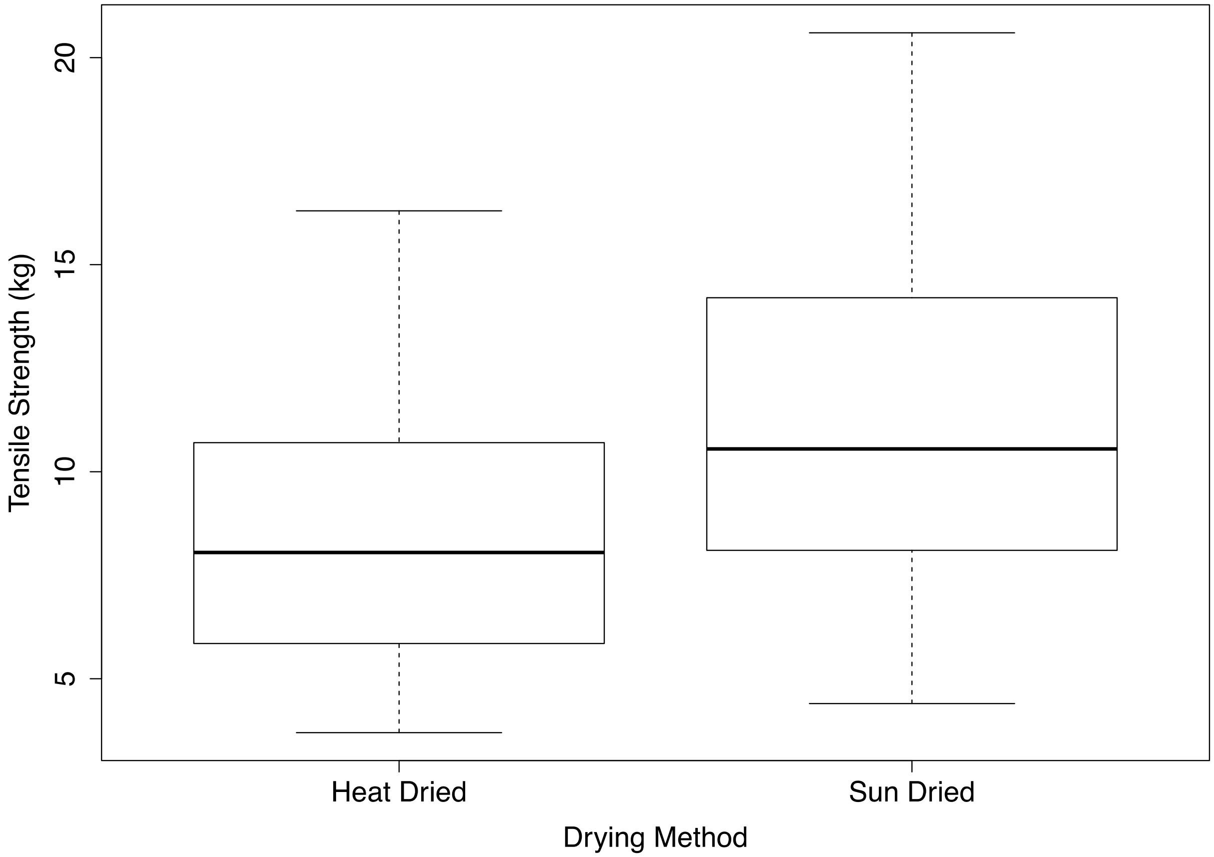

Figure 8. Boxplot showing the tensile strengths of *Pandanus tectorius* leaves after being dried using two different methods. The dark line represents the mean tensile strength. The horizontal walls of the box represent the first and third tensile strength quartiles. The outermost “whiskers” illustrate the minimum and maximum tensile strength of their respective drying method (Paired t-test, t = 5.18, df = 51, p-value < 0.001).