Morphological Characters of Papaya (*Carica papaya* L.) for Drought Tolerance

Pablito M. Magdalita*
Institute of Crop Science
University of the Philippines Los Baños

Institute of Plant Breeding
University of the Philippines Los Baños

Michael R. Noel(+)
Edna A. Aguilar
Institute of Crop Science
University of the Philippines Los Baños

Alangelico O. San Pascual
Institute of Plant Breeding
University of the Philippines Los Baños

ABSTRACT

Papaya plants (*Carica papaya* L.) were assessed for tree and fruit morphological traits. During eight months of drought conditions, papaya plants showed signs of drought from March to May 2016. Drought affected fruit development and fruit qualities. Significant decrease in fruit weight, length, width, flesh thickness, and seed weight were observed in drought-affected papayas; however, total soluble solids (TSS) of fruit flesh were significantly higher compared to the TSS of fruits harvested during normal conditions. Drought-tolerant papaya trees were selected based on morphological responses. Drought-tolerant papaya trees were significantly taller and had thicker stems, wider crowns, and more functional green leaves compared to drought-affected trees. Selected plants that thrived well under drought condition were identified for use in breeding. Recovery of plants was evident in increase in fruit weight, length, and width. Correlation of fruit characters of selected drought-tolerant papaya trees revealed that fruit weight was strongly positively correlated with fruit length, fruit width, peel weight, flesh thickness, and TSS.

Keywords: Carica papaya, drought, fruit characters, recovery, tree characters

* *Corresponding Author*

INTRODUCTION

The papaya (*Carica papaya* L., 2n=18), a monotypic species in the family Caricaceae, is commonly grown for its melon-like fruits, which are available throughout the year. It is relatively easy to grow and produces fruits within a short period of time, making it a good cash crop. If grown under the right conditions, papaya can produce high yield per tree and on a per hectare basis. In 2020, a total of 163,299.41 metric tons were produced in the Philippines. Papaya ranked 10^{th} in area planted and 4^{th} in production volume among the ten leading fruit crops in the Philippines (PSA 2021). The top three papaya-producing regions were SOCSARGEN (64,113.16 metric tons), Northern Mindanao (38,030.41 metric tons), and Davao Region (10,619.2 metric tons) (PSA 2021). About 92% of the total papaya production is consumed locally as food and the rest is for industrial uses.

Papaya suffers from several diseases and pests—the most widespread and destructive of which is the Papaya Ringspot Virus (PRSV). The PRSV was first detected in Silang, Cavite in 1982 (Opina 1986), but it spread rapidly in Luzon and in other islands like Marinduque, Mindoro, Panay, Negros, Bohol, and Cebu, to name a few, because of the explosive nature of the disease (Magdalita et al. 1989). In 2001, PRSV was detected in a few areas in Davao del Sur and South Cotabato in Mindanao (Herradura 2001) but did not spread because of vigilant sanitation and quarantine measures.

In the Philippines, PRSV practically decimated commercial papaya cultivation in Southern Luzon, leading to significant declines in papaya production, which then caused substantial losses of income to farmers, a relative scarcity of the fruit in the market, and higher costs to consumers (Magdalita et al. 2016). However, in Hawaii, the transgenic “Rainbow” variety is resistant to PRSV. In the Philippines, the moderately PRSV-tolerant variety “Sinta” has been used for planting by farmers in Luzon since 1995. Bacterial crown rot (BCR) causing 100% damage to papayas at any stage of growth is another limiting factor to production. Breeding for tolerance to BCR via regrowth selections is underway at the Institute of Plant Breeding, College of Agriculture and Food Science, University of the Philippines Los Baños (Magdalita et al. 2016).

Aside from PRSV and BCR, papaya production is also constrained by abiotic factors such as drought during summer months and beyond, waterlogging, and strong wind especially during typhoons. There are almost 20 typhoons that visit the country each year (PAGASA 2016). Tall papaya trees with heavy leaves and large canopies in general can be toppled by strong winds and also suffer from too much water brought by heavy rains, causing rotting of the roots. Thin-stemmed papayas also cannot withstand limited water and can become weak, causing them to fall to the ground, particularly if loaded with fruits.

The availability of water in the soil affects papaya physiology and productivity. It has been reported that papaya plants exhibit both stomatal and non-stomatal responses to soil water deficits, and the sources of these response signals are both hydraulic and non-hydraulic in nature (Campostrini and Glenn 2007). Marler et al. (1994) proposed that it is highly unlikely that stomata of drought-stressed papaya plants closed due to hydraulic signals from leaf dehydration since leaf relative water content and pre-drawn xylem potential (Ψ_{pd}) were unrelated to gravity (*g*) at mild and moderate soil water deficits. It was also proposed that other non-hydraulic plant signals are controlling stomatal behaviour. Non-hydraulic signals such as abscisic acid and jasmonic acid (but not indole-3-acetic acid) differed in their accumulation patterns under stress. Jasmonic acid initially increased and then decreased in leaves and roots. Mahouachi et al. (2007) proposed abscisic acid as an accumulative, non-hydraulic hormonal signal that could be involved in the induction of several physiological responses in papaya under progressive water stress such as the reduction in gas exchange parameters and leaf abscission. They further suggested that delaying dehydration appears to be the adaptation that papaya uses in response to drought, even though osmotic adjustment was not demonstrated. However, Mahouachi et al. (2006) found that osmotic adjustment is a contributing factor in drought adaptation in papaya varieties such as Baixinho de Santa Amalia**.** Marler et al. (1994) and Torres-Netto (2005) demonstrated that there is genetic variability in papaya cultivar response to soil water deficits, providing clues to the mechanisms of drought adaptation. However, these constraints can be overcome by developing and designing papaya line/s and hybrids with multiple disease resistance and tolerance to drought. This kind of variety has been sought by many papaya growers, especially those in the drought-prone areas of the country. Beneficial architectural characteristics of papaya plants desired by papaya growers include the following: stout and sturdy trunk that holds more water and resists wind; dwarf habit that escapes wind; erect leaves and shorter petioles that drain rainwater quickly; bigger roots that anchor the tree better on the ground; and fast maturing so that it can escape typhoons and drought.

Like any agricultural crop, the papaya has a narrow range of adaptations to climatic elements for optimum and maximized productivity. Characterization of papaya responses to natural conditions (in situ) is important to establish the genotype-by-environment interactions based on anticipated fluctuations of climatic elements and edaphic factors, taking into account the temporal variability of the production areas. In terms of drought, tolerant lines/varieties should be selected and developed despite the narrow range of adaptation because of the pressing issues of drought in this time of climate change. To develop such lines, documentation and comparison of responses under drought and non-drought conditions are vital for the development of lines with drought tolerance in terms of drought tolerance traits.

This study aimed to: i) determine the association of different traits of drought-tolerant and non-drought affected (pre-drought or normal) papaya trees; and ii) evaluate the morphological responses, such as tree and fruit characters, of drought-tolerant and non-drought-tolerant (drought phase) papaya trees, drought affected and non-drought affected trees (pre-drought phase or normal condition), and the trees that recovered after the drought condition (recovery or post-drought phase).

MATERIALS AND METHODS

Ninety plants of *C. papaya* L. variety "Sinta" were planted on December 23, 2014 in Tranca, Bay, Laguna in a replicated trial. The plants were planted 3 m apart between rows and 2.5 m between plants. The plants were provided with the recommended cultural practices for fertilization, irrigation and pest control. For fertilization, basal application of 1:1 complete fertilizer and urea before the planting of seedlings and monthly application of 100g of the aforementioned mixture were implemented. Watering during seedling stage whenever needed was observed. Application of pesticides whenever needed was also implemented. The cultural management of papaya was based on The Philippine Recommends for Papaya (PCAARRD 2006).

During the normal condition, tree parameters such as plant height (m), stem diameter (cm), crown diameter (cm), and number of green leaves were gathered. The plant height was measured using a meterstick from the base to the top of the tree, while the stem diameter was measured using a Vernier caliper. The crown diameter was measured at the largest canopy spread using a meterstick, while the green leaves were counted from the most mature leaves to the last fully expanded leaves.

At first fruiting (normal condition), 10 physiologically mature fruits from each sample tree were harvested at Peel Color Index 2 (PCI 2), i.e., when a tinge of yellow appears on the apex of the fruit, and allowed to ripe completely on a ripening rack. At full ripe stage, fruit characters such as fruit weight (g), fruit length (mm), fruit width (mm), peel weight (g), peel thickness (mm), flesh thickness (mm), total soluble solids (TSS, °Brix), and seed weight (g) were assessed. The fruit weight, peel weight, and seed weight were determined using an automatic top-loading balance while fruit length, fruit width, peel thickness, and flesh thickness were measured using a Vernier caliper. The TSS was measured using a digital refractometer (Milwaukee

Instruments, Inc., 2950 Business Park Drive, Rocky Mount, North Carolina 27804, USA). Juice extracts from each fruit were dropped into the refractometer and the digital reading of TSS was recorded.

During the eight months of drought throughout the dry season of 2016, the papaya trees were especially affected by drought in the months of March, April, and May, during which there were spikes in temperature with an average of 31−35°C and no rainfall observed. The data on temperature and other climatic data were retrieved from the National Agrometeorological Station based in Los Baños (Figure 1).

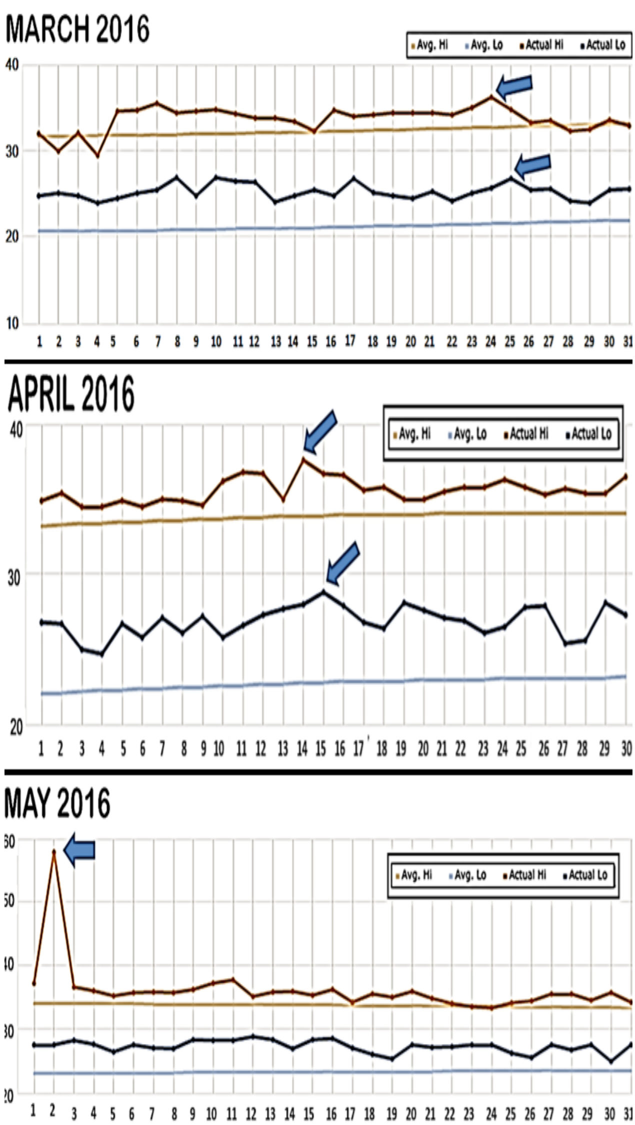

Figure 1. Actual and average daily high and low temperatures (ºC) at Tranca, Bay, Laguna from March to May 2016. The blue arrows represent spikes in temperature. Data from the National Agrometeorological Station in Los Baños.

Again, tree characters and fruit qualities mentioned above were assessed to compare the effect of drought with normal condition (Figure 2). Drought-subjected plants were planted in an identified drought-rainfed area in the Central Experiment Station at the Institute of Plant Breeding. During this set-up, no rainfall was recorded for three months; hence, the plants were identified to be under drought condition. Plants that were irrigated based on recommended water management practices for papaya were identified as those under normal condition. In addition, drought-tolerant trees that thrived well under drought condition and showed good vigor and fruiting ability were selected and identified as putative drought-tolerant trees (Figure 3).

Figure 2. Papaya plants in the papaya breeding block, B4, Tranca, Bay, Laguna (A) before drought and (B) after drought.

Figure 3. Fruits of drought-affected papaya trees and those that were grown under normal condition.

After the drought condition, the trees were again evaluated to assess the ability of the drought-affected trees to recover from drought. The same tree and fruit characters mentioned above were evaluated. In addition, the association of tree and fruit characters of drought-tolerant and normal papayas was determined.

For the statistical design and analysis, the experiment was laid out in Randomized Complete Block Design with three replications. Twenty tree samples were used in each replication for the evaluation of tree characters. Twenty ripe fruit samples for each sample tree in a replicate were used in the evaluation of fruit characters. All data gathered was subjected to one-way analysis of variance using the STAR statistical package (IRRI 2014). The significance of means was tested using Student t-test at 0.05 level of significance.

RESULTS AND DISCUSSION

Morphological characteristics of putative drought-tolerant and non-drought tolerant papayas were evaluated. Results showed that drought-tolerant papayas were significantly taller, had thicker stem diameter and wider crown, and had more green leaves compared to drought-affected papayas (Table 1). Generally, tree height, stem diameter, crown diameter and number of green leaves were reduced in drought-affected trees (Table 1). This reduction in tree characters of drought-affected trees is probably due to reduced photosynthesis resulting in decreased growth. Taiz and Zeiger (2010) discussed that, as water content in the plant decreases, the cells tend to shrink and relax. This also causes a decline in cell volume, causing lower turgor pressure following the solute concentration in the cell. Further, they stated that as there is water deficit, plasma membrane becomes thicker and then more compressed, making the area of the cell smaller. The changes in turgor pressure affect the expansion of different organs such as leaves and roots. These organs are sensitive to turgor changes, which in turn make then sensitive to drought (Taiz and Zeiger 2010) Similar observations were recorded for wheat (*Triticum sativum* L.) where water deficiency had an inhibitory effect on plant growth (Pireivatlou et al. 2008). Further, the authors observed that dry matter accumulation in the kernels was decreased by water deficit. The dry weight of vegetative organs was also decreased during the grain filling period under stress condition.

Table 1. Selected tree morphological characters of selected drought-tolerant and drought-affected papaya plants at fruiting stage in a drought-affected condition

Condition	Tree height (m)	Stem diameter (cm)	Crown diameter (m)	No. of leaves
Drought-Tolerant Trees	3.2 a	9.2 a	6.2 a	25.4 a
Drought-Affected Trees	1.8 b	6.2 b	4.1 b	19.5 b
Reduction (%)	43.75	32.61	33.87	23.23

Means with the same letter are not significantly different at 0.05 level.

The results showed that drought significantly affected the fruit development and fruiting habit of papaya (Table 2). Generally, trees grown under drought condition produced fewer number of fruits than the trees grown under normal condition (Figure 2). Few (1–4) to no fruits developed under drought-affected conditions while 5–18 fruits were observed in papayas grown in normal condition. Papaya trees grown in the field throughout the eight months of drought during the dry season of 2016 were highly affected especially during the months of March, April and May during which there were spikes of high temperatures (Figure 1).

Table 2. Fruit characters and fruit character % reduction of drought-affected papaya trees in comparison with drought-tolerant papaya trees and papaya trees grown in normal condition

Condition	Fruit weight (g)	Fruit length (mm)	Fruit width (mm)	Peel weight (g)	Peel thickness (mm)	Flesh thickness (mm)	Total soluble solids (ºBrix)	Seed weight (g)
Drought-affected vs. Normal Condition								
Trees under normal condition	1,400.3 a	170.5 a	132.7 a	96.7 a	13.6 a	35.5 a	10.6 b	159.3 a
Drought-affected trees	400.4 b	85.5 b	57.8 b	87.7 b	11.6 a	21.7 a	13.6 a	54.7 b
Reduction in fruit characters (%)	71.41	49.85	56.44	9.3	14.7	38.87	-28.30	65.66
Drought-tolerant vs. Drought-affected								
Drought-tolerant trees	800.5 a	143.4 a	111.5 a	90.5 a	13.4 a	22.5 a	14.4 a	55.6 a
Drought-affected trees	400.4 b	85.5 b	57.8 b	87.7 b	11.6 a	21.7 a	13.6 a	54.7 a
Reduction in fruit characters (%)	49.98	40.37	48.16	3.09	13.43	3.55	5.56	1.62

Means with the same letter are not significantly different at 0.05 level.

It could be surmised that under drought condition, papaya flowers that develop tend to turn into fruit but they eventually aborted due to lack of water; hence, fruit development is hampered and yield is reduced. This can also be observed in the decreased number of flowers that set into fruits. In drought conditions, 0–10% of the papaya flowers set to become fruits while 70–80% of the flowers set to become fruits under normal condition. This finding is similar to a recent report that mungbean (*Vigna radiata* L.) grown under drought condition also had reduced yield (Adorada et al. 2019).

In terms of fruit characters, the drought-tolerant papaya trees had significantly higher fruit weight, fruit length, fruit width, peel weight, peel thickness, flesh thickness and seed weight than the drought-affected papaya trees (Table 2).

In general, the abovementioned fruit characters were reduced among the drought-affected trees, but not in the drought-tolerant trees. This is due to the limited fruit development caused by lack of water, resulting in limited photosynthesis and translocation of photosynthates of the tree. According to Zhang et al. (2019), this restricted photosynthesis is attributed to the decrease in the chloroplast's carbon-fixing enzyme activity and metabolic pathways' changes.

However, TSS of fruits harvested under drought was significantly higher compared to TSS of fruits (10.6±0.09) harvested under normal condition (Table 2). This higher TSS observed among fruits of drought-affected papaya trees is due to the higher accumulation of reducing sugars like fructose, which is likely more concentrated than those found in trees grown under normal condition. While the fruits borne by the drought-affected trees are smaller, their flesh is sweeter than those borne by trees grown under normal condition. The TSS of fruits from drought-affected trees was 35.85% higher than the TSS of fruits from trees grown under normal condition. Similarly, in sugar apple (*Annona squamosal* L.), sugar increased in fruits of drought-stressed trees compared to well-watered trees (Kowitcharoen et al. 2018). Furthermore, the present finding agreed with a previous report that mild drought improved the fruit quality relating to hexose sugar accumulation, flesh firmness and organic acid content (Van de Wal et al. 2017). The present result also corroborated previous findings that drought causes fructose levels in peach fruit to increase because heat causes higher rates of photosynthesis, increasing sugar levels in the fruit (Alexandra 2012). In drought-stressed plants, the observed increased sugar level concentration was due to the plants' adjustment to osmotic homeostasis (Giné-Bordonaba and Terry 2016).

The results showed that fruit development and fruit qualities of papaya are significantly affected when exposed to prolonged drought condition. For example, the fruits of drought-affected trees are generally small, while the fruits of hermaphrodite trees are deformed (Figure 3). Fruit deformation occurs in hermaphrodite trees where the stamens become carpelloidic and produce deeply ridged or irregular shaped fruits called "cat-faced". This condition is most probably due to the high temperature and low soil moisture during drought (Purseglove 1968). In addition, this result corresponded with a previous report that drought causes fruit deformation and fruit size reduction in raspberry (*Rubusidaeus*) (Morales et al. 2013). However, it is interesting to note that some trees were identified as putative drought-tolerant since they can withstand drought, develop a regular crown with green leaves, and still bear fruits (Figure 4).

Figure 4. Selected drought-tolerant papaya trees based on tree characters at first and second fruiting cycle.

These trees are good selections as sources of drought-tolerant traits in breeding for drought tolerance in papaya. After further purification followed by screening, selection of drought-tolerant individual plants can be done to increase their breeding value.

Table 3. Fruit characters of papaya trees grown during normal condition, drought, and recovery phase after a drought condition

Conditions	Fruit weight (g)	Fruit length (mm)	Fruit width (mm)	Peel weight (g)	Peel thickness (mm)	Flesh thickness (mm)	Total soluble solids (ºBrix)	Edible portion (%)	Seed weight (g)
Normal (Pre-drought)	1,533.08 a	195 a	132.46 a	107.32 a	17.0 a	28.31 a	11.42 b	87.17 a	89.82 a
Drought	400.4 c	85.5 c	57.8 c	87.7 b	11.6 c	21.7 c	13.6 a	84.2 b	85.1 b
Recovery phase	1,395.5 b	175.3 b	125.5 b	88.65 b	15.5 b	25.9 b	10.2 b	84.2 b	85.1 b
Recovery from drought (%)	71.31	51.17	53.94	0.97	24.68	15.44	-33.33	3.86	35.72

Means with the same letter are not significantly different at 0.05 level.

The morphological responses in terms of fruit qualities of putative drought-tolerant and drought-affected papayas and those that recovered after drought are presented in Table 3. The recovery of the plants after drought was shown by an increase in value of the different characters such as fruit weight (71.31%), fruit length (51.71%) and fruit width (53.84%), but not TSS. This is possible because TSS, a relative measure of reducing sugars in papaya, is affected by water during the recovery phase when the trees are rehydrated, thus diluting its concentrations in the fruit and resulting in the decrease in value. This indicates that the fruit traits at recovery stage returned to sub-normal conditions wherein they are similar to those observed during the normal condition or pre-drought stage.

Fruit characters observed during the recovery stage are within the range of the values observed during the normal condition or pre-drought stage. This result is in agreement with a previous finding in soybean (*Glycine max* L.) that after rehydration the plant height and leaf area exhibited an increase in value (Dong et al. 2019).

However, since the trees were already older during the recovery stage, their fruit characters were no longer similar to those traits shown by the papaya trees during the normal condition or pre-drought condition when the trees were still young and very vigorous. Concomitant to this result, it was found in maize (*Zea mays* L.) that, after reuptake of water of a plant subjected to drought, most of the physiological parameters like leaf water content, water potential, osmotic potential, gas exchange, and chlorophyll content returned to normal levels (Chen et al. 2015). In addition, after reuptake of water, plant growth, and photosynthesis became normal as shown by growth of new plant parts (Xu et al. 2010).

Phenotypic correlation of different characters of drought-tolerant papaya trees showed weak to strong positive correlation (Table 4). Fruit weight has strong positive correlation with fruit length (0.81), fruit width (0.75), peel weight (0.91),

Table 4. Phenotypic correlation among different characters of the selected drought-tolerant papayas

	PH	SD	CD	CH	LP	GL	FWt	FL	FW	PW	PT	FT	TSS	SW
PH	1.00													
SD	0.22	1.00												
CD	0.34	0.43	1.00											
CH	0.23	0.56	0.60	1.00										
LP	0.25	0.46	0.62	0.90	1.00									
GL	0.10	0.63	0.26	0.41	0.28	1.00								
FWt	-0.01	0.28	0.11	0.12	0.08	0.10	1.00							
FL	0.11	0.33	0.15	0.09	0.05	0.27	0.81	1.00						
FW	0.11	0.38	0.14	0.09	0.02	0.37	0.75	0.93	1.00					
PW	0.02	0.23	0.14	0.11	0.09	0.07	0.90	0.83	0.78	1.00				
PT	-0.17	0.24	0.12	0.14	0.15	0.21	0.69	0.82	0.83	0.73	1.00			
FT	-0.03	0.40	0.09	0.12	0.12	0.26	0.78	0.88	0.91	0.80	0.89	1.00		
TSS	0.03	0.36	0.03	0.16	0.19	0.17	0.71	0.83	0.84	0.72	0.82	0.92	1.00	
SW	-0.02	0.12	0.01	0.01	-0.06	0.21	0.56	0.64	0.71	0.59	0.58	0.61	0.53	1.00

PH- plant height, SD- stem diameter, CD- crown diameter, CH- crown height, LP- length of petiole, GL- no. of green leaves, FWt- fruit weight, FL- fruit length, FW- fruit width, PW- peel weight, PT- peel thickness, FT- flesh thickness, TSS- total soluble solids, SW- seed weight flesh thickness (0.78), and TSS (0.71), indicating that the fruit weight of drought-tolerant papayas is strongly correlated with several traits. This finding corroborated a previous result that fruit weight of rambutan (*Nephellium lapaceum*) is also strongly positively correlated with fruit length, fruit width, and seed weight (Magdalita and Valencia 2004). In addition, the present result coincided with an earlier report on jackfruit, another hardy and drought-tolerant species of fruit crop, indicating that fruit weight is strongly positively correlated with fruit length and fruit width (Magdalita et al. 2011).

Fruit length is also strongly positively correlated with peel weight (0.83), peel thickness (0.82), and TSS (0.83). The same has been observed between fruit width and peel weight (0.78), fruit width and peel thickness (0.83), fruit width and TSS (0.84), and fruit width and seed weight (0.71). These results indicate that fruit length and fruit width are strongly correlated with several fruit morphological traits, including the sugar content of the flesh of the fruits of drought-tolerant papaya trees.

A similar observation was made in avocado, a relatively known hardy fruit, that fruit length is correlated with flesh thickness, while fruit width has strong positive correlation with seed width (Magdalita and Valencia 2004). Also in the present study, peel weight is correlated with flesh thickness (0.73), peel thickness (0.80) and TSS (0.72). Similarly, peel thickness has strong positive correlation with flesh thickness (0.89) and TSS (0.82). Furthermore, papayas with thick flesh could also have high TSS, suggesting they could be sweet.

However, very weak to no correlation existed between peel weight and plant height (0.02), and TSS and plant height (0.03). Also, there was very weak positive correlation between crown diameter and flesh thickness (0.09), crown diameter and TSS (0.03), and crown diameter and seed weight (0.08). Furthermore, the number of green leaves and peel weight had very low positive correlation (0.07). This finding suggests that these non-correlated characters are independent from each other and that they are unique characters of drought-tolerant papayas. The present result corroborated a previous finding in known drought-tolerant fruit crops like jackfruit where fruit weight had little correlation with fruitlet width, fruit weight, and percent of edible portion (Magdalita et al. 2011).

SUMMARY AND CONCLUSION

The drought-tolerant papayas were significantly taller and had thicker stem diameter, wider crown, and more green leaves compared to drought-affected papayas. Drought significantly affected the fruit development and fruiting habit of papaya in that trees grown under drought condition produced fewer number of fruits than trees grown under normal condition. However, the TSS of papayas under drought was significantly higher compared to TSS of fruits under normal condition.

Selected drought-tolerant papaya trees had significantly higher fruit weight, fruit length, fruit width, peel weight, peel thickness, flesh thickness, and seed weight than the drought-affected papaya trees. However, the abovementioned fruit characters were reduced among the drought-affected trees. Fruit development and fruit qualities of papaya were significantly affected when exposed to drought condition. The fruits of drought-affected trees were generally small, while the fruits of hermaphrodite trees were deformed. After drought, recovery of the papaya trees was shown by an increase in value of the different characters, such as fruit weight (71.31%), fruit length (51.71%), and fruit width (53.84%), but not TSS. A strong positive correlation was detected among different fruit characters. Fruit weight was strongly and positively correlated with fruit length (0.81), fruit width (0.75), peel weight (0.91), flesh thickness (0.78), and TSS (0.71).

Overall, drought affected the growth and fruit development of papaya but the selected drought-tolerant trees had better stature, thicker stem diameter, wider crown, and more green leaves compared to drought-affected papayas. In addition, selected drought-tolerant papaya trees had heavier, longer, and wider fruits with thicker peel and flesh and heavier seeds than fruits from drought-affected papaya trees. The morphological responses to drought of papaya are important information for the selection of lines with drought tolerance. The selection based on the responses to drought can be used to identify putative lines that can be used to create hybrids and utilize heterosis for increased drought tolerance to produce drought-resilient papaya varieties in the future.

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Dr. Pablito M. Magdalita <pmmagdalita@up.edu.ph > is a Professor and UP Scientist III at the Institute of Crop Science, and an affiliate researcher and plant breeder at the Institute of Plant Breeding, College of Agriculture and Food Science (CAFS), University of the Philippines Los Baños (UPLB). He also teaches horticulture and plant breeding courses at UPLB. His research is focused on fruit breeding and biotechnology.

Dr. Edna A. Aguilar is a Professor at the Institute of Crop Science, CAFS UPLB. She is currently teaching advanced crop and fruit physiology, and farming systems courses. Her research endeavors are focused on farming systems and fruit physiology.

Mr. Alangelico O. San Pascual, M.Sc. is a University Research Associate II at the Institute of Plant Breeding, CAFS UPLB. He is currently involved in plant breeding projects involving fruits and ornamentals.

Mr. Michael R. Noel, M.Sc.(+) was a former University Researcher at the Institute of Crop Science, CAFS UPLB. His short stint at the institute was focused on understanding the effect of drought and other adverse conditions on fruit crop production.