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PHYSIOLOGICAL MATURITY OF FRUITS AND SEEDS OF LUANTI ACCESSION CASTOR (*Ricinus communis* Linn).

Charlene Cory C. Hilarion.[1*], Jupikely James Silip[1]

[1]Faculty of Sustainable Agriculture, Universiti Malaysia Sabah Sandakan Campus,
Beg Berkunci No.3, 90509 Sandakan, Sabah, Malaysia

*Corresponding Author

ABSTRACT

Castor (*Ricinus communis* L.) has indeterminate maturity which makes it hard to determine its harvest time. Few studies have examined castor fruit and seed changes during maturation for harvesting and postharvest handling. This study was conducted to determine castor fruit maturity index and seed physicochemical characteristics at different maturity index. Luanti accession castor fruit at different maturity stages was sampled from 21 days after anthesis (DAA) until the fruit turned brown at 49 DAA for maturity index determination. Then, castor seeds were sampled at different maturity index for physicochemical analysis. All data was analysed using SPSS version 21. Result shows that Luanti accession castor can be described into four maturity indices (young green, mature green, dried green and ripe brown). Physiological maturity occurred at 35 DAA. Seed physical characteristics was found to be significantly different at different maturity index ($p<0.05$), while there was no significant difference in castor seed chemical characteristics ($p<0.05$). Castor can be harvested at any maturity index for oil production since there is no significant effect on its oil quality. The only constraint in harvesting castor is the difference in the seed oil content at different maturity index.

Keywords: castor, maturity index, seed physiochemical characteristics, *Ricinus communis*

INTRODUCTION

Castor plant (*Ricinus communis* Linn) of the Euphorbiaceae family is an oilseed crop with high economic value. It has indeterminate maturity due to its indeterminate growth habit. The flowering and fruiting of castor in the same inflorescence or raceme do not occur at the same time (Anjani, 2012; David et al., 2013) and successive generations of racemes continue to sprout before the primary raceme enters full maturity stage, resulting in the existence of mature and immature racemes at the same time (Baldanzi et al., 2002; Vallejos et al., 2011; David et al.,

ISSN: 2455-6939

Volume:03, Issue:06 "November-December 2017"

2013). The heterogeneity maturity nature of castor causes difficulty in determining the whole raceme maturity making it hard to decide the right harvest time for castors.

Crop is considered to reach maturity when it had completed its natural growth and development and to be ripe when it has undergone maturation or reached a condition of full development (Reid, 2011). Castor fruit is considered to reach physiological maturity stage when it starts to undergoes maturation drying (Schmidt, 2007), while its seed is considered to be at physiological maturity when it is capable of full germination after drying even before reaching final stage of maturation albeit with poor vigour of growth (Moshkin, 1986).

In crop production, it is crucial to determine crop maturity index as it affects quality perception and the rate of quality changes during postharvest handling (Shewfelt, 2014). Maturity index can be used as measurement to determine crop maturation. There are still limited literature on castor maturity index especially information on maturity index for increasing extractable oil yield (da Silva et al., 2009). Castor fruit physical and seed oil content changes had rarely been used for castor fruit maturity index determination since previous studies mainly focused on characterising castor seeds development and physiological quality (Chen et al., 2004; da Silva et al., 2009; Fanan et al., 2009; Houston et al., 2009; Zuchi et al., 2009; Cagliari et al., 2010). This study aims to characterize castor crop maturation process by observing its fruit and seed development changes at different maturity stages for harvesting recommendation. Fruit physical and oil content changes were used as maturity indicators since fruit changes can be easily observed without destructive sampling. Oil content on the other hand is the main product of castor. Therefore, the objectives of this study are 1) to determine castor fruit maturity index, 2) to determine seed physicochemical characteristics at different maturity index.

METHODS

Plant material

Castor plant from Luanti accession was obtained from the experimental field of the Universiti Malaysia Sabah, Sandakan Campus. Castor was planted by direct sowing at 0.06 m depth in planting bed size 3.00 m x 1.00 m x 0.15 m and spaced 0.30 m apart. Five castor plants were planted in each planting bed with 0.50 m within row and 1.30 m between rows spacing. Vermi-compost at 6 t/ha was applied as basal treatment and left for one week before the sowing process. NPK Blue fertilizer (12-12-17-2) was applied at 0.06 t/ha at third week and sixth week after planting. The plants were watered once a day early in the morning with watering rate of 9,000 L/ha. Weed was controlled by using manual method, while chemical insecticide was used to control pest attack.

ISSN: 2455-6939

Volume:03, Issue:06 "November-December 2017"

Sampling procedure

Fruits from the primary raceme were randomly sampled for this study. Three fruits were sampled from the top, middle and bottom part of each raceme. The sampling for fruit maturity index determination began at 21 DAA with seven days intervals until the fruit turned brown at 49 DAA. The sampling for seed physicochemical characteristics was conducted based on the fruit maturity index (index 1 = young green fruit, index 2 = mature green fruit, index 3 = dried green fruit, index 4 = ripe brown fruit). The fruit samples were sealed in plastic bags and were immediately brought to the laboratory for the analysis.

Fruit physical characteristics

Fruit colour was measured by using Konica Minolta Colour Meter (CR-100 Minolta Corp. Japan). The measurement was expressed as lightness (L*), chroma (C*) and hue (h^o). The L* value is the intensity of colour which ranged from zero (i.e. black) to 100 (i.e. white), while the C* value is the purity of colour. The h^o value is the dominant colour in the colour chart of 360^o, with 0^o, 90^o, 180^o and 270^o representing red, yellow, green and blue colour, respectively. Castor fruit colour was determined by using Follett and Sanxter (2000) method.

Fruit size was measured by using length and width. Fruit length was measured by using vernier calliper from the distal end of fruit to the point of fruit proximal end, while the width was measured at the widest midpoint of each fruit. Fruit fresh weight was measured by using an electronic analytical balance.

Fruit moisture content was determined using Zuchi et al. (2009) method. Fresh fruits were weighed using electronic analytical balance before and after drying at 105^{o}C for 24 h. The fruit moisture content was calculated according to the dry weight basis formula:

$$\text{Moisture content \%} = \frac{\text{Wet weight} - \text{dry weight}}{\text{Wet weight}} \times 100$$

Oil content

Crude castor oil was extracted from its seeds by using soxhlet extraction method with 95% ethanol as a solvent. The seeds were treated according to the drying treatment method in Akpan et al. (2006). Seeds were first oven-dried at 60^{o}C for 7 h before it was crushed. Approximately 10 g of dry crushed seeds with 300 mL ethanol were refluxed for 6 h at 70^{o}C in a Soxhlet extractor. The extracted oil was obtained by using rotary evaporator to separate the solvent at 70^{o}C. The extracted oil was heated in the oven at 70^{o}C for 30 min before being weight. The extracted crude oil was kept in a closed container and stored in a refrigerator at 4^{o}C for

ISSN: 2455-6939

Volume:03, Issue:06 "November-December 2017"

subsequent analysis. The oil content or extractable oil yield was measured by using the percentage by weight according to the formula:

$$\text{Oil content \%} = \frac{\text{Weight of extracted oil}}{\text{Weight of sample before extraction}} \times 100$$

Seed physical characteristics

Seed size is measured by using length, width and thickness as seed size index. The length, width and thickness were measured with vernier calliper as mentioned in the measurement of fruit size. The thickness was measured at the thickest parts of the seed.

The 100-seed weight was determined based on the modified method in Seyed et al. (2011). Hundred seed weight was calculated by weighing 10 seeds randomly using electronic scale and extrapolating the result to 100 seeds.

Seeds moisture content was determined by using low constant temperature oven method according to ISTA (2005) method. Approximately 1.0 g seeds were dried at 103°±2ºC for 17±1 h for the moisture content determination. The seeds were placed in a desiccator and allowed to cool for 45 minutes before weighing. The moisture content was calculated according to the dry weight basis formula:

$$\text{Moisture content \%} = \frac{\text{Wet weight} - \text{dry weight}}{\text{Dry weight}} \times 100$$

Seed chemical characteristics

The seed chemical characteristics were determined based on the crude castor oil analysis. Refractive index value was measured by using a digital refractometer (Atago Model N1). The refractometer was calibrated using distilled water before it was used to test the oil sample.

Free fatty acid (FFA) in castor oil was determined by using modified method by Kyari (2008). A mixture of 5.0 g castor oil was mixed with 12.5 mL diethyl ether and 12.5 mL ethanol in a conical flask before a few drops of phenolphthalein was added to the mixture. Then, the mixture was titrated with 0.1 M sodium hydroxide (NaOH) with consistent shaking until the mixture turn into a dark pink colour. The FFA and acid value were calculated as follows:

$$\text{FFA value \%} = \frac{\text{Volume of NaOH used in titration (mL)}}{\text{Weight of sample (g) x 2.83}} \times 100$$

Acid value % = 2 x FFA value.

ISSN: 2455-6939

Volume:03, Issue:06 "November-December 2017"

Saponification value in castor oil was determined by using the modified method in Lubrizol (2013). A mixture of 2 g castor oil with 25 mL of 1 N ethanoic potassium hydroxide and 25 mL of neutralized alcohol was boiled gently for 60 minutes with a reflux condenser. Then, 1 mL of phenolphthalein was added to the warm mixture. Next, the mixture was titrated with 1 N hydrochloric (HCl) acid until the pink colour disappeared. The same procedure was repeated with a blank. Saponification value was calculated as follows:

$$\text{Saponification value} = \frac{56.1 \times \text{HCl actual normality} \times (\text{Vol of HCl used for blank} - \text{Vol of HCl used for the test})}{\text{Mass of sample}}$$

Statistical analysis

The experimental design used in this study was a completely random design. Fruit colour, fruit size, fruit fresh weight and seed size determination was conducted by measuring 100 individual fruits and seeds respectively. Fruit and seed moisture content, oil content, and seed chemical characteristics determination was conducted in five replication. The 100-seed weight determination was conducted in 10 replications. Data were analysed using ANOVA (SPSS V21) and mean separation was carried out using Tukey's HSD test with a significant difference at $p<0.05$.

RESULTS

Castor fruit maturity index

Luanti accession castor fruits was observed to turn to a dark green colour at 21 DAA and remained in green stage until 35 DAA. After 35 DAA, the fruit begin to undergo maturation drying and split open while still in green stage, thus this stage is regarded as the dried green stage. The fruits gradually turns brown without entering the yellowing stage. The fruit was fragile during the dried green and ripe brown stage as it is easily shattered.

Fruit colour value varied significantly at different maturity stages at $p<0.05$ (Table 1). At 21 DAA until 35 DAA green stage, the fruit light, chroma and hue values were not significantly different. The light values showed no significant changes at 42 DAA dried green stage, but the chroma values increased significantly by approximately 34.62% and hue values decreased significantly by approximately 22.16%. The hue values at 42 DAA dried green stage were significantly different with 21 DAA and 35 DAA green stages, but not with 28 DAA green and 49 DAA ripe brown stage. Fruit light and chroma decreased significantly by approximately 27.68% and 54.29% respectively, at ripe brown stage as the colour become darker.

ISSN: 2455-6939

Volume:03, Issue:06 "November-December 2017"

Fruit length, width and weight also varied significantly at different maturity stages at $p<0.05$ (Table 1). The fruit length and width increased significantly by 5.33% and 4.90% respectively, from 21 DAA to 28 DAA green stages and then decreased significantly by 8.99% and 6.43% respectively, at 35 DAA green stages. The fruit length and width continued to decrease by 8.02% and 5.63% respectively as it reached 42 DAA dried green stage. At 49 DAA ripe brown stage, the fruit length and width increased significantly by 2.68% and 2.65% respectively as the fruits split open. Fruit weight from 21 DAA to 28 DAA green stages was not significantly different. The weight decreased significantly by approximately 7.55% at 35 DAA green stages. At 42 DAA dried green stage, the fruit weight continued to decrease significantly by 58.37%. However, there was no significant difference in fruit weight between the fruit at 42 DAA dried green and at 49 DAA ripe brown stage.

Fruit moisture content varied significantly at different maturity stages at $p<0.05$ (Table 1). At 21 DAA and 28 DAA green stages, there was no significant difference in the fruit moisture content. The moisture content decreased significantly by approximately 9.73% at 35 DAA green stage, but there was no significant difference between 28 DAA and 35 DAA green stages. Fruit moisture content continued to decrease by 57.80% from 35 DAA to 42 DAA dried green stage and by 70.04% at 49 DAA ripe brown stage.

Castor seed oil content varied significantly at different maturity stages at $p<0.05$ (Table 1). At 21 to 28 DAA green stages, there was no significant difference in castor oil content. The oil content increased significantly by approximately 39.96% at 35 DAA green and by 15.10% at 42 DAA dried green stage. At 49 DAA ripe brown stage, castor oil content reached the highest level with an increased by 8.92% from 42 DAA dried green stage.

International Journal of Agriculture and Environmental Research

ISSN: 2455-6939

Volume:03, Issue:06 "November-December 2017"

Table 1: Luanti accession castor fruits physical characteristics and oil content changes during castor fruit development and maturation at different days after anthesis (DAA)

Maturity stages	Colour value			Length (cm)	Width (cm)	Weight (g)	Moisture content (%)	Oil content (%)
	L^*	C^*	h^o					
21 DAA Green	41.0±2.71a [z]	22.7±4.13b	114.7±3.87a	1.69±0.07b	1.63±0.08b	2.72±0.34a	79.30±2.77a	28.08±0.53d
28 DAA Green	41.1±2.03a	23.6±11.99b	115.3±3.34ab	1.78±0.09a	1.71±0.09a	2.83±0.04a	71.78±1.96ab	29.37±2.09d
35 DAA Green	40.6±2.98a	23.8 132.00b	128.9±3.29a	1.62±0.08c	1.60±0.07c	2.57±0.03b	68.19±0.89b	40.21±1.83c
42 DAA Dried green	37.8±29.93a	31.5±33.61a	93.1±39.59bc	1.49±0.05e	1.51±0.06e	1.07±0.02c	28.77±8.29c	46.28±1.14b
49 DAA Ripe brown	29.0±3.77b	14.4±6.69c	79.1±3.35c	1.53±0.06d	1.55±0.07d	0.98±0.02c	8.62±3.47d	50.41±0.56a

L^* = lightness, C^* = chroma, h^o = hue

[z]Mean followed by the same letter within each column are not significantly different by Tukey's HSD multiple comparison at $p<0.05$

ISSN: 2455-6939

Volume:03, Issue:06 "November-December 2017"

Seed physical characteristics according to maturity index

Castor seed length, width and thickness varied significantly at different maturity index at $p<0.05$ (Table 2). The seed length decreased by 0.85% from young green to mature green stage and continued to decrease by 5.17% at dried green stage. At ripe brown stage, the seed length had decreased by 0.91%. Castor seed width decreased by approximately 5.33% from young green stage to dried green stage, but there was no significant difference between seed width at mature green and dried green stage. Seed width increased by approximately 2.82% as it reached ripe brown stage. Castor seed thickness decreased by 7.27% from young green to mature green stage and continued to decrease by 1.96% as it entered ripe brown stage.

The 100-seed weight also varied significantly at different maturity index at $p<0.05$ (Table 2). There was no significant difference between castor 100-seed weight at young green and mature green stage. The 100-seed weight gradually decreased by approximately 16.15% from mature green to dried green stage and decreased by 15.91% as it reached ripe brown stage.

Castor seed moisture content was also found to vary significantly at different maturity index at $p<0.05$ (Table 2). The seed moisture content decreased by 45.85% from young green to mature green stage and by 55.46% as it reached dried green stage. There was no significant difference in seed moisture content at dried green and ripe brown stage.

Castor seed chemical characteristics at different maturity index

Castor refractive index, free fatty acid (FFA), acid, and saponification values were found to have no significant difference at different maturity index at $p<0.05$.

Table 2: Luanti accession castor seed physical and chemical characteristics at different maturity index

Maturity index	Seed physical characteristics					Seed chemical characteristics			
	Length (cm)	Width (cm)	Thickness (cm)	Hundred seed weight (g)	Moisture content (%)	Refractive index at 25ºC	Free fatty acid value (%)	Acid value (%)	Saponification value
Young green	1.17±0.05a[z]	0.75±0.04a	0.55±0.04a	19.73±a	58.14±4.34a	1.478±0.00	0.92±0.23	1.83±0.45	176.56±4.83
Mature green	1.16±0.04b	0.71±0.03c	0.51±0.26b	20.14a	31.48±2.41b	1.479±0.00	1.08±0.18	2.16±0.36	178.80±7.26
Dried green	1.10±0.03c	0.70±0.23c	0.49±0.01c	16.72b	14.02±4.27c	1.479±0.00	1.11±0.28	2.21±0.55	181.67±11.82
Ripe brown	1.09±0.04d	0.73±0.32b	0.50±0.02bc	14.06c	9.22±0.44c	1.480±0.00	1.17±0.16	2.33±0.32	184.37±8.46

[z]Mean followed by the same letter within each column are not significantly different by Tukey's HSD multiple comparison at $p<0.05$

ISSN: 2455-6939

Volume:03, Issue:06 "November-December 2017"

DISCUSSION

Castor fruit maturity index

Based on the results from the observation in castor fruit physical and oil content changes, castor can be categorized into four maturity indices, namely young green, mature green, dried green and ripe brown stage (Table 1). Castor fruits in 21 DAA and 28 DAA green stages are considered to be in the same maturity index (i.e. young green stage) because there was no significant difference in the fruit colour values, fruit weight, fruit moisture content and seed oil content (Table 1). Although there was a significance difference in the fruits length and width, the size changes did not correlates with the oil changes during the fruit developmental stages. Maturity index should be established based on both the physical and chemical changes during the period of fruit maturation and not by physical changes alone (Crisosto, 1994; Reid, 2011). Thus, it can be concluded that fruit at 21 DAA and 28 DAA belong in the same maturity stages. Young green fruit is considered to reach its full fruit growth stage at 28 DAA since it reached its full size at this stage.

Castor fruit is considered to reach its physiological maturity or mature green stage at 35 DAA because it undergoes maturation drying at this stage. The maturation drying result in the decreased of fruit size and weight (Table 1). Castor fruit is a dry fruit with orthodox seeds and similar to other dry fruits, it will begin to dry at physiological maturity in order to cracked open after ripened (Schmidt, 2007). Castor fruit had been reported to change its colour to yellowish brown at physiological maturity, but Luanti accession castor fruit did not show any significant colour changes at physiological maturity (Lavanya et al., 2012).

The dried green and ripe brown stage is considered to be in different maturity index due to the difference in their oil content (Table 1). The changes in oil content corroborates previous studies that oil content will increase with fruit maturation and slows down at the end of ripening stage (Canvin, 1963; Moshkin, 1986; Chen et al., 2004; Pinto et al., 2012). In addition, there was a significant difference in the fruit colour, size and moisture content (Table 1).

Fruit at dried green and ripe brown stage showed a significant difference in their light and chroma values (Table 1). However, there was no significant difference in the hue value between dried green and ripe brown stage, and between dried green and 28 DAA young green stages (Table 1). The results supported previous studies that the hue value of an object may be similar but vary in light and chroma value (Kuehni, 2005). The hue value at dried green stage was 93.1^{o} which is in the range between yellow (90^{o}) and green colour (180^{o}), while the hue value at ripe brown stage was 79.1^{o} is in the range between red (0^{o}) and yellow (90^{o}) colour. The results corroborate previous study that in brown colour, the human eyes perceived redness and

ISSN: 2455-6939

Volume:03, Issue:06 "November-December 2017"

yellowness (Kuehni, 2005). The hue values indicate that fruit at 28 DAA young green is greener than fruit at dried green stage.

The brown stage is regarded as the ripe stage since castor is considered to reach ripe stage when its fruit is in dehiscent stage (Greenwood and Bewley, 1982; Moshkin, 1986; Chen et al., 2004). Dried green stage cannot be considered as ripe stage since not all fruits in dried green stage are dehiscent. Moreover, fruit lost its green colour at ripening due to chlorophyll breakdown as the fruit prepared to enter senescence stage to separate from its mother plant (Rees and Hammond, 2002; da Silva et al., 2009; Barry and Roux 2010; Severino and Auld, 2013; Shewfelt, 2014). The decreased in light and chroma values at ripe brown stage reflected the process of chlorophyll breakdown that occurred as castor entered its senescence stage (Table 1).

The results showed that single parameter cannot be used as maturity indicator for castor. It is difficult to differentiate the green stages of Luanti accession castor by using colour value because there was no significant difference in the fruit light, chroma and hue at 21 DAA until 35 DAA green stages which indicated that there was no noticeable colour changes (Table 1). The best indicator for castor is its oil content for it provides objective measurement to describe castor maturation. The oil content can be used with other parameters such as fruit colour, size and weight. Fruit length, width and weight were found to be the best indicator for young and mature green stage, while the dried green and brown stage can be differentiated based on its colour. Fruit moisture content was found to be a poor indicator since not all maturity indices had significant difference in their moisture contents (Table 1). In addition, it is difficult to accurately estimate the fruit moisture content since it is affected by weather conditions during fruit development and maturation.

Castor seed physicochemical characteristics at different maturity index

Castor seed size, weight and moisture content was observed to decrease at mature green stage because the seed will undergo rapid phase of dehydration at physiological maturity as the seeds entered desiccation stage and mother plant ceases photosynthates translocation (Table 2; da Silva et al., 2009; Severino and Auld, 2013). Therefore, the seed moisture content will decreases while the oil content increases as water is excluded from the interior of the hydrophobic oil bodies (Tables I – II; Chen et al., 2004; Pinto et al., 2012; Bewley et al., 2013). Moshkin (1986) reported that seed moisture content reached 30 to 50% at physiological maturity and similar level of moisture content had been observed in Luanti accession castor at physiological maturity (i.e. 31.48%; Table 2).

The results proved that castor maturity index based on fruit physical and oil content changes can be used to describe castor maturation since it can be associated with the seed physiological maturity. Moreover, it also showed that fruit physical characteristics are more suitable to be used

ISSN: 2455-6939

Volume:03, Issue:06 "November-December 2017"

as maturity indicator compared to seed physical characteristics. The seed size, weight, and moisture content at some maturity index were found to have no significant difference (Table 2). The seed physical characteristics are also influenced by environmental factors and the mode and time of harvest (da Silva et al., 2009; Warra et al., 2011; Severino and Auld, 2013).

Castor seed chemical characteristics were found to have no significant difference at all maturity index. Therefore, in regards to oil quality, castor can be harvested at any maturity index since there will be no effect on castor oil quality. This finding is similar to Ogunniyi (2006) that reported castor oil quality to be hardly affected by the seed quality. The only constraint in harvesting castor is the difference in the seed oil content at different maturity index.

CONCLUSION

This study has shown that fruit physical and oil content changes can be used to determine castor fruit maturity index since it can be associated with castor seed maturation. Castor fruit can be categorized into four maturity indices, namely young green, mature green, dried green and ripe brown stage. The results indicate the best maturity indicator for castor fruit are fruit colour value and seed oil content. Castor fruit reach physiological maturity at 35 DAA when the fruit is still green in colour (i.e. 40.6 L*, 23.8 C*, 128.9 h^o) and oil content is approximately 40.21%. Fruit physical changes were found to be a better maturity indicator compared to seed physical changes. Seed chemical characteristics were found to have no significant difference with maturity index. Therefore, the only constraint in harvesting for castor oil production is the significant difference in castor oil content at different maturity index. Further study on postharvest treatment to increase castor crude oil extraction is recommended.

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ISSN: 2455-6939

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Volume:03, Issue:06 "November-December 2017"

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