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Fruit development of groundcherry (*Physalis angulata* L.) in dryland

Diana Nurus Sholehah[1,3], Sucipto Hariyanto[2], Hery Purnobasuki*[2]

[1]Doctoral Study Program of Mathematics and Natural Science, Faculty of Science and Technology, Airlangga University, Surabaya, Indonesia
[2]Department of Biology, Faculty of Sciences and Technology, Airlangga University, Surabaya, Indonesia
[3]Program of Agroecotechnology, Faculty of Agriculture, University of Trunojoyo Madura, Bangkalan, Indonesia

***Correspondence: hery-p@fst.unair.ac.id[2]; dianans@trunojoyo.ac.id[1,3]**

Abstract

Physalis angulata are widespread in the tropics with high bioactive compounds and pharmacological effects. This paper aims to identify the stages of fruit development and changes in physicochemical properties to provide comprehensive data on optimal fruit utilization. This study used CM 1 accession found in Madura Island with purplish stems and fruit peels. After 30 days of cultivation, the plant was transplanted into a polybag containing red Mediterranean soil and manure (5:1). It is grown in a greenhouse for 90 days to observe. The experimental design was completely randomized. The stages were selected as treatments: 1, 3, 6, 9, 12, 15, 18, and 21 Day After Anthesis. The study used 15 replications with a total of 15 plants used, except for chemical analysis which used five replication with three plants for each replication. Observations were carried out during the reproductive phase and the parameters included fruit phenology, physical character, and chemical characteristics. The result showed that the growth stage of *P. angulata* consists of fully opened flower, fruit development (fruit set and fruit expansion), and ripening fruit (starting ripe, advanced ripe, and eating ripe). The optimal fruit stage for consumption is 21 days after anthesis, which has a diameter of 13.58 mm, a weight of 1.69 g and firmness of 3.40 N, total soluble solids of 14.96 Brix, total titratable acid of 0.0011%, and vitamin C 20.91 mg/100 g.

Keywords: BBCH; Agricultural land; chemical characteristics; physical characteristics; phenology
Abbreviations: BBCH_Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie; DAA_day after anthesis; TTA_total titratable acidity; TSS_total soluble solid.

Introduction

Physalis is a genus of the *Solanaceae* Family with the highest number of phytochemical-rich species out of 2300 species belonging to this family (Medina-Medrano et al., 2015). This species easily adapts to different environmental conditions, such as different types of climate. It can grow in a wide range of environments, evidenced by the anatomical plasticity of leaves favouring more excellent radiation resistance (Rodrigues et al., 2014). It causes the species to spread from the subtropics such as Asia, Columbia, Brazil, Peru, and Africa to the tropics (Muniz et al., 2014). Ozaslan et al*.* (2017) reported on an invasive plant in Turkey.
This species is a monoecious plant with pale yellow single flowers on the axillary leaves (Figueiredo et al., 2020). It bear flowers and fruits throughout the year (Muniz et al., 2014). *Physalis* fruit has interesting physical properties with a distinctive taste, aroma, juicy and crunchy texture and attractive colour (Oliveira et al*.*, 2016).
P. angulata is also known as groundcherry. It has become the centre of attention because of the nutritional and bioactive compounds that provide important body health benefits (Kusumaningtyas et al., 2015; Saavedra et al., 2019). The primary components are physalin and withanolide groups. The three groups of physalin are physalin B, F, and G. A form of withanolide is withangulatin. Anti-inflammatory, anti-tumour, cytotoxic, anti-carcinoma and trypanocidal properties are all present in both (Sun et al., 2017; Meng et al., 2019). Another important content is antioxidant compounds from phenolic groups such as flavonoids, phenolic acids, and coumarin (Lima et al., 2014). These compounds have also been shown to function as immunomodulators (Kusumaningtyas et al., 2015). According to the study conducted by Medina-Medrano et al. (2015), antioxidant compounds in this species have the highest DPPH scavenging and total antioxidant capacity compared to 5 other *Physalis* species. The fruit showed the highest antioxidant activity (Ferreira et al., 2019) and cytotoxic effect (Iwansyah et al., 2019). Demand for this fruit has recently risen, followed by the rise in production and commercialization of Physalis to other regions of the world (Muniz et al., 2015; Oliveira et al., 2016).
Despite numerous research, it is essential to comprehend fruit growth and development and their impact on fruit quality, from seed to harvest. This data will be used to determine maturity index, which is currently unavailable. Determining ripeness is critical for deciding the best harvest

time for fresh markets and processing, such as nutritional foods and traditional medicine (Neves et al., 2017).

Growing environments also significantly influence the rate and period of plant growth and development, which ultimately affects the physicochemical characteristics of fruits, such as their weight, size, and soluble solid (Barroso et al., 2018). The studies on the impact of the growing environment on fruit characteristics lead to understand the possibility of growth of the species in various areas, such as drylands. There is a critical need to consider drylands adapt to climate change, as they will change the phenology of plant growth and senescence. A core aspect of global change studies is the study of biological life cycles, such as phenology and fruit production (Walker et al., 2015). Understanding plant phenological behaviour is critical for improving production and determining proper cultivation management (Ghrab et al., 2016).

This study aims to identify the stages of fruit development and changes in physicochemical properties to provide comprehensive data on optimal fruit utilization in dryland. In this study, there was a comprehensive presentation of fruit development analysis from anthesis until ripe. The aspects of fruit development consist of the phenology and physicochemical change based on BBCH scale

Result and Discussion

Fruiting phenology

The growth stage of groundcherry fruit based on the BBCH scale consists of stages 65, 70, and 80 (Table 1). Fully opened flowers mark stage 65, absiced petals indicate expansion fruit at stage 70, while the ripening stage occurs at stage 80. Observations were carried until eating ripe at 21 DAA because the fruit fell off over that age. The plant in this study begins to produce flowers after the branches formed, and the formation of other flowers follows this. The transformation from the vegetative to the generative stage is represented by this occurrence (Ramirez et al., 2013). Groundcherry flowered during the reproductive phase until senescence (Figueiredo et al., 2020). The first flower emerged time was 12 days after transplanting. That time was earlier than the result of Sadiyah et al. (2020).

Stage 65 is characterized by a fully opened flower with perpendicular petals to the pedicel. The open flowers had an average diameter of 12,67 mm. The flowers begin to open randomly from 06:00 to 12:00 and start to close at 15:00 and close entirely at 17:00 daily, in line with the petal movement time of Figueiredo et al. (2020). In this study, the flowers opened for 8-9 hours. Flower that open less than that will return to open the next day until they meet the opening time. Anther opened and released pollen for the fertilization process as soon as the flower opened. Flower opening rhythmics are generally related to circadian rhythms and pollination activity with pollinators (Fenske et al., 2018). Environmental signals such as light, temperature, and nutritional status may influence the circadian clock of flowers (Horibe, 2018, Inoue et al., 2018). The anthesis flowers are closed and dried together with the anthers the next day (Figueiredo et al., 2020). The dried petals fall or remain between the tips of the calyx, which turn into calyx that cover the fruit. The process occurred for three days and indicated the beginning of stage 70. The early part of fruit development is the growth of ovaries known as fruit sets, followed by cell division and fruit expansion (Handa et al., 2011; McAtee et al., 2013). The success of the fruit set determines the fruit yield. Temperature and humidity were the predominant environmental factors in tomato fruit sets (Shamshiri et al., 2018). The size and weight of the fruit increase rapidly, and the stage lasted for 12 days.

Stage 81 represents the beginning of the ripening process that occurs at 12 DAA. Harvest was performed at 21 DAA (stage 89). A previous study stated that the fruit ripe based on optimal seed maturity occurred 28 days after anthesis at an average daily temperature of 24-27°C (Santiago et al., 2019). According to Hatfield and Prueger (2015), temperature improves phenological growth by increasing senescence. The reproductive phase is more sensitive to temperature increases than the vegetative phase. The higher daily average temperature of this study (40.27°C) is believed to accelerate ripening. Physical and chemical changes characterize the maturation process.

Physical characteristics

Physical changes include size, weight, firmness, and colour change. The size and weight increase toward the end of the measurement period, but the rate decreased at 12 - 21 DAA (fig 2). The weight and diameter of the fruit at 21 DAA are similar to the values obtained by Santiago et al. at the ideal harvest fruit stage (2019). The weight and size increase shows the accumulation of dry matter in the pulp and seeds (Liguori et al., 2014). The variations may be attributed to the ripening state, in which the fruit, climate, and soil properties were planted along with the genotype (Oliveira et al., 2016, Purquerio et al., 2019). Texture modifying occurs during the ripening process. The activated ethylene-induced significantly changed the shape and composition of the cell wall and leads to the softening of pericarp tissue (Tucker et al., 2017). Firmness decrease began to occur 12 DAA, and The lowest firmness was 3.39 N in 21 DAA. This value was higher than the ripe *P. peruviana* fruit firmness in Oliveira et al. 2016 with 2.94 N. According to Sadiyah et al. (2020), calyx accession from Madura has a higher firmness than other regions in East Java. The chromatic coordinate values are shown in Fig 3. The value of a* was negative at the beginning of the fruit growth and showed a green colour on calyxes and fruit peels up to 12 DAA and 6 DAA, respectively. Yellow discolouration of the calyx and peel occurred during maturation. This is supported by the increasing positive b* value at 15-18 DAA ranging from 30.06 - 31.07. The intensity was below the *P. peruviana* with b* value of 57.94 (Oliveira et al., 2016). The value of b decreases at 18 DAA, while the L* value increases up to 21 DAA. A positive L* value represents increased redness and the reddish-purple colour on the calyx and peel. It is different from the latest study in Madura by Sadiyah et al. (2020), which reported that ripe fruits have green skin. The appearance of purple pigments in many fruits is associated with the presence of anthocyanins. In certain fruits, the purple colour was associated with fruit maturity, and the levels reach maximum in the final stages of fruit development (Khoo et al., 2017).

Chemical characteristic

According to Souza et al. (2017), *Physalis* has a high carbohydrate level at the fruit growth phase. This level will decrease when the carbohydrates are broken down into sugar at the fruit ripening phase, increasing the soluble solid levels. The content of organic acids, sugars, and other dissolved solids is a soluble solid component that affects fruit taste. The soluble solid levels increased rapidly after entering the 12 DAA, but the increase begins to slow down at the end of fruit life (Fig 3). The highest soluble solid levels were 21

Table. 1 Growth stage of *Physalis angulata* fruit.

Stage	BBCH Description	BBCH *Physalis angulata*	DAA
60	Flowering		
65	Fully open flower	Fully open flower	0
70	Fruit Development		
71	Fruit set	Fruit set; Petal dries or abscised; calyx closed; fruit about to grow	1
72	20 % fruit growth	Fruit reached 20% final weight	3
75	50 % fruit growth	Fruit reached 50% final weight	6
77	70 % fruit growth	Fruit reached 50% final weight	9
80	Fruit Maturity		
81	Starting of ripening	Start of rapid increase soluble sugar and softening	12
85	Advanced ripening	Calyx and fruit peel turned to yellow, enhanced softening	15
88		Slow softening, calyxs turned to slightly brownish, and fruit peels started to have purple tinge and seed maturation	18
89	Eating ripe	Completely mature: fruits have typical fully ripe, yellow with an intensive purple tinge, starting abscission of the fruit	21

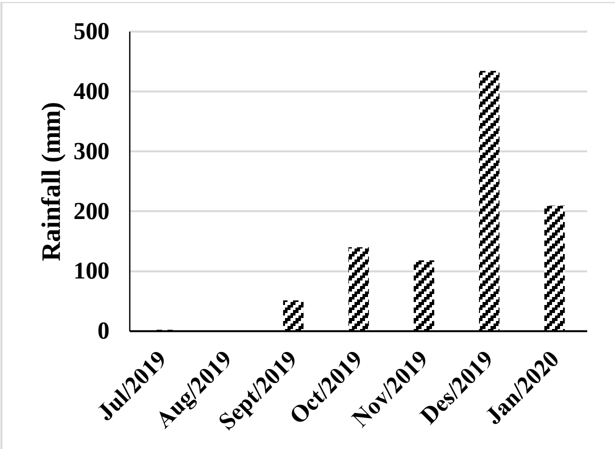

Fig 1. Monthly rainfall during the development of groundcherry in the years 2019 and 2020.

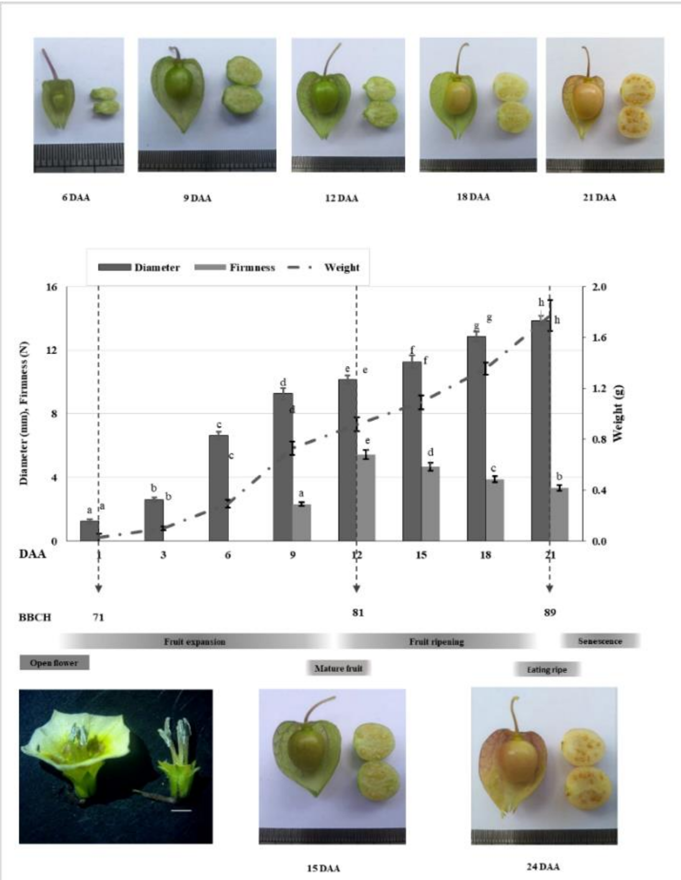

Fig 2. Fruit Development of *Physalis angulata* Base on BBCH Scale from Open Flower to Eating Ripe. Bar = 2 mm.
Averages followed by the same letter in the same bar do not differ by DMRT test (P<0.05).

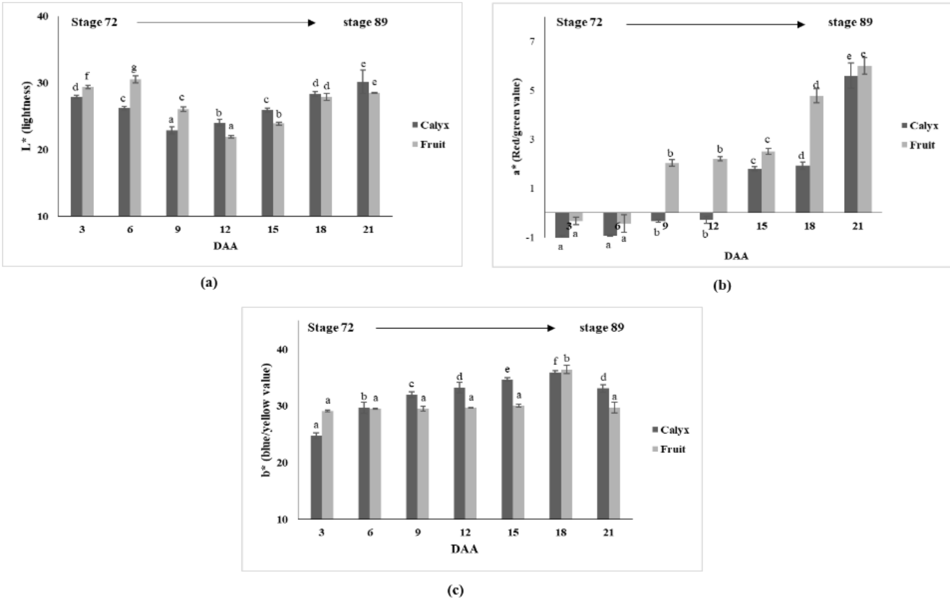

Fig 3. Colour of *P. angulata* fruit and calyx indicated by L*, a* and b* value. (a) L* (lightness) (b) a* (red / green value) (c) b* (Yellow / blue value). Averages followed by the same letter in the same bar do not differ by DMRT test (P<0.05).

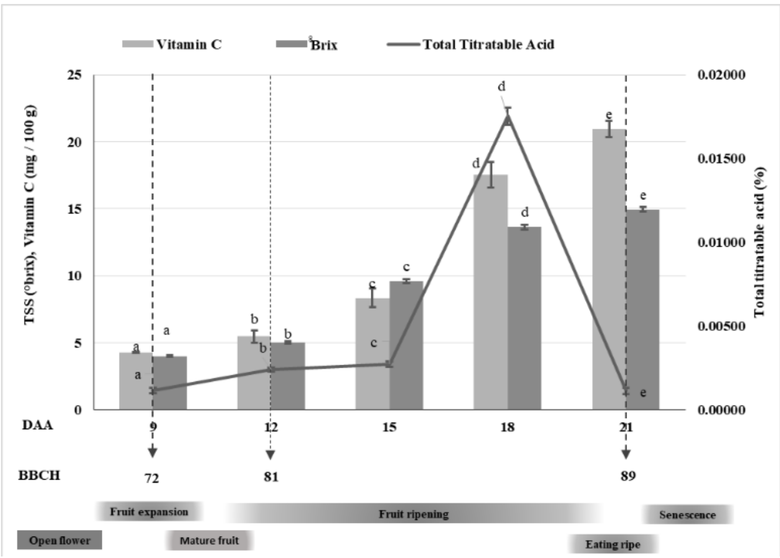

Fig 4. Some important chemical characteristics of *P. angulata* fruit aligned to BBCH scale . Averages followed by the same letter in the same bar do not differ by DMRT test (P<0.05).

DAA with 14.96˚Brix, higher than the study by Curi et al. (2018) and Souza et al. (2017) with 12 and 11.3˚Brix, respectively. In contrast, the total titratable acid decreased to a minimum level at 21 DAA with 0.0011%. The acid decrease affects consumer preferences for fruit selection. Sweet fruit and low acidity are preferred by consumers and suitable for fresh consumption (Souza et al., 2012). The vitamin C level was 20.91 mg / 100 g, below the study results conducted by Curi et al. (2018), reaching 75.44mg / 100 mg.

Material and Methods

Plant material and location of the experiment

The experiment was carried out from October 2019 to February 2020. The plants are cultivated in Bangkalan Madura (112˚E44'9,176"E and -7˚2'47,652"S) which was a dryland under a wet climate (Dwiratna et al., 2018) with low-moderate monthly rainfall (Fig 1) and annual rainfall of 1662 mm, an average daily maximum temperature of 40.27˚C at an altitude of 5 m above sea level. This study used CM 1 accession found in Madura Island. It was characterized by a purplish stem and fruit peel, according to Sholehah and Setiawan (2019). The plant growth medium was a red mediterranean soil:manure (5:1) in a polybag. The plants were transplanted 30 days after sowing and cultivated for 90 days in the greenhouse for observation. The experimental design was completely randomized with development stages of fruit as treatments. The stages were selected as treatments: 1 DAA, 3 DAA, 6 DAA, 9 DAA, 12 DAA, 15 DAA, 18 DAA and 21 DAA (Fig 1). The study used 15 replications with a total of 15 plants, except for chemical analysis which used five replication with three plants for each replication.

Five fruits of each plant were collected for each stage and taken to the laboratory.

The data obtained were analyzed with analysis of variance (ANOVA). Then The means were compared with Duncan Multiple Range Test (DMRT) at 5 % significance.

Phenological monitoring

Phenological observations were carried out on flowers and fruits. Information about flower initiation, longevity, and degree of opening of the petals was systematically collected. At the beginning of the study, the flowers were checked every four hours. The flowers were only observed from 0500 hours to 2100 hours if it was not open overnight. The fruiting phenology is presented based on physicochemical changes from anthesis flowers through ripe fruit according to the BBCH scale (Hack et al., 2013, Ramirez et al., 2013). These data were used to characterize the fruit development study.

Physical characteristics

The physical characteristics include the diameter, weight, colour, and firmness of the fruit. Digital callipers measured the diameter with a sensitivity of 0.01 mm. The weight was measured using a digital balance with a sensitivity of 0.01 mg.

The fruit colour was measured using a colour reader (Konica Minolta - CR -10) by measuring L*, a*, and b*. L* represents the value of dark or light, a* represents the variation value from red to green (a positive value = red, a negative value = green), while b* represents the variation value from blue to yellow (b positive value = yellow, b negative value = blue) (Yildiz et al., 2015). Its colour parameter is widely used in agroindustry and effectively determines slight colour variation (Odjo et al., 2012).

The fruit firmness was measured using the TA.XT texture analyzer tool. The tool's setting includes a 2 mm probe, a test speed of 1.00 mm/s, and a distance of 6 mm from the observation. The firmness value is obtained in newtons (N).

Chemical characteristics

some critical chemical characteristics of the fruit, including TSS, TTA and vitamin C. The TTA was determined using titration according to the Association of Official Analytical Chemists (AOAC, 2000). Two grams of fruit juice were dissolved in 50 ml of purified water. Then 25 ml filtrate of the mixture was added to three drops of phenolphthalein 1 %. The mixture was titrated with 0.1 N sodium hydroxide (NaOH) until it turned to a stable pink colour. The total titratable acidity was expressed in terms of TTA (%) as the amount of 0.1 N NaOH per 100 mg fruit, according to the following equation :

$$\text{TTA (\%)} = \frac{(\text{V} \times o.1 \times 100)}{m}$$

Where: 0.1 is the normality of NaOH (N), V is the volume of NaOH required (ml), and m is the mass of the fruit juice sample used (mg).

Vitamin C was determined using a modified method of redox titration by Ciancaglini et al. (2001). Two grams of fruit juice were dissolved in 50 ml of purified water. The mixture of 25 ml filtrate was then added to 1 ml of starch indicator drops and then titrated with 0.01 N iodine until it turned to a stable blue colour. The vitamin C content can be calculated according to the following equation:

$$\text{Vitamin C (mg / 100 g)} = \frac{\text{V} \times 0{,}88 \times \text{P} \times 100}{\text{Ws}}$$

V is the volume of iod 0.01 N (ml), P is the dilution factor of the fruit sample, 0.88 is a converted factor of 1 ml for 1 ml iod 0.01 N ascorbic acid milligram, and Ws is the sample weight (g).

Conclusion

In conclusion, the growth stage of *P. angulata* includes fully opened flower, fruit development (fruit set and fruit expansion), and ripening fruit (starting ripe, advanced ripe, and eating ripe). Based on growth conditions, the ripe fruit has a diameter of 13.58 mm, weight 1.69 g, firmness 3.40 N, soluble solid 14.96, total titratable acid 0.0011%, and vitamin C content of 20.91 mg / 100 g. Eating ripe fruit is the optimal condition for consumption at 21 DAA with maximum fruit size, yellow with purple tinge fruit, soft juicy texture, and sweet taste. The sugar level and the level of titratable acid influenced the unique taste of the fruit.

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