Determination of Seed Physiological Maturity of *Ipomoea reptans* Poir. Based on Phenology, Seed Quality, and Heat Unit Accumulation

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Abstract. Kangkong (*Ipomoea reptans* Poir.) seeds have different colors at harvest due to differences in the seed maturity level, hence, differences in seed quality. Therefore, this study aimed to obtain information about the phenology of flowers, fruits, seeds, and to determine the appropriate heat unit accumulation to reach the seed physiological maturity of kangkong when the maximum seed quality is achieved. The experiment was arranged in a randomized completely block design with one factor. The experimental factor was the seed harvest age consisted of 15 levels, starting from 16 days after anthesis (DAA) or 79 days after planting (DAP) to 30 DAA. The anthesis occurred at 63 DAP. The results showed that the seed physiological maturity of kangkong cv KK02 was achieved at 25 DAA with the characteristics of brownish fruit color, white seeds, and the seeds turned dark brown after drying. At 25 DAA, the seed moisture content was the lowest while the seed dry weight, seed viability, and seed vigor reached their maximum. The heat unit of kangkong cv KK02 at the seed physiological maturity was 1,668.50 °Cd. It is suggested that the kangkong seeds are harvested at 25 DAA with a heat unit of 1,668.50 °Cd.

Keywords: Days after anthesis · Harvest age · Seed dry weight · Seed viability · Seed vigor

1 Introduction

Kangkong (Ipomoea reptans Poir.) is one of the most popular leafy vegetables in Southeast Asia especially Indonesia due to its good taste and cheap price. The plant can produce optimum yields in tropical lowland conditions. The ideal temperature for the growth of kangkong is around 25–30 °C, while temperatures below 10 °C cause damage to the plant [1]. This plant is easily cultivated either by planting the seeds or by its stem. Moreover, this fast-growing leafy vegetable can be sequentially harvested for long period about 4–5 months [2]. Kangkong seeds are harvested when the fruit is ripe. Harvesting is done by pulling the kangkong plant and removing the roots, then the plants are stored in the field for several days in dry weather conditions. This is done to ensure that all the seeds will ripen at the same time [3]. However, kangkong seeds have different colors

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at harvest, this is influenced by differences in the seed maturity level, hence, different seed quality. This problem has been faced by a seed company in Indonesia. Therefore, it is important to find the seed physiological maturity of kangkong when the seed can be harvested at its maximum quality.

The use of quality seeds is one of the key successes of agricultural production. The maximum seed quality occurs at its physiological maturity. Seeds that have reached physiological maturity have maximum seed dry weight and seed vigor. Although the physiologically immature seeds can germinate, however, the vigor and germination rate are lower than the seeds that have reached physiological maturity. The right harvest time can maximize yield and seed quality [4].

To estimate accurately the time from anthesis to harvest when the seed reaches its physiological maturity, calculation of the heat unit or growing degree days is needed. The heat unit method is a quantitative method of the relationship between temperature and plants. Temperature is a factor that represents the availability of energy for plant growth and development. The base temperature of the plant is needed to calculate the accumulated heat unit [5]. Plant development depends on temperature and requires a specific amount of heat to develop from one stage in their life cycle to another, such as from seeding to the harvest stage [6]. Our previous work on cucumber revealed that the heat unit of seed physiological maturity (29 days after anthesis) was 979.8 °Cd when the dry weight, seed viability, and vigor were maximum [7]. The growth and development of kangkong plant show good performance under the sun [8]. There is no information available on the kangkong seed maturity based on the accumulation of the heat unit. Therefore, the use of this method is expected to increase accuracy in determining the seed harvest time.

This present study also observed the phenology of the kangkong plant starting from flowering to the end of the harvest time as it related to our objective to determine physiological maturity. Phenology is the science of the periods of naturally occurring phases in plants that are influenced by environmental conditions, such as length of irradiation, temperature, and humidity [9]. Phenology has recently received great attention because there have been changes in the timing of the development stages of plant species as a consequence of the relatively modest levels of climate warming. It is now an important area of climate impacts research. [10]. Our previous study on cucumber [7] and long bean [11] showed useful information about the time to reach the seed physiological maturity and the morphology of the fruits and seeds at certain stages of their development.

To date information on physiological maturity and ideal harvest time of kangkong seeds is not available. Therefore, the present study was undertaken to find information about the phenology of flowers, fruits, seeds, and to determine the appropriate heat unit accumulation to reach the seed physiological maturity of kangkong when the maximum seed quality is achieved.

2 Materials and Methods

2.1 Experiment Time and Place

The experiment was carried out from February to June 2020 at the Cikabayan Bawah Experimental Station, Dramaga Campus of IPB University, geographically at 6° 33′

05.0″ south latitude and 106° 42′ 55.6″ east longitude. The rainfall in Dramaga from February to June 2020 ranged from 246.2 to 705.3 mm month^{-1}, the lowest and highest temperatures at the time of the study were 22.16 °C and 31.68 °C with an average temperature of 26.4 °C [12].

The harvested seeds were tested for quality at the Seed Laboratory, Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University.

2.2 Experimental Material

The kangkong seeds of cv KK02 were obtained from PT. BISI International Tbk, Jember, East Java.

2.3 Procedure

The experiment was arranged in a randomized completely block design with one factor. The experimental factor was the seed harvest age consisted of 15 levels, starting from 16 days after anthesis (DAA) or 79 days after planting (DAP) to 30 DAA.

The procedure of plant cultivation included land preparation, seed planting, maintenance, harvest, and post- harvest. Experimental observations were carried out by observing the phenology of flowers, fruits, and seeds, from flowering to the last harvest. The quantitative characters of flowers include the length of the stalk, the diameter of the stalk, the length of the petal (corolla), and the width of the petal. The qualitative character of the flower is the color of the petal. The quantitative characters of fruit include fruit weight, fruit length, and fruit diameter. The qualitative character of the fruit observed was the color of the fruit before and after being dried in the sun. The quantitative characters of the seeds include seed length, seed width, number of seeds per fruit. The qualitative character of the seeds observed was the color of the seeds after drying. The samples observed were 30 flowers, 30 fruits, and 100 seeds. Calculation of plant heat units was based on data obtained from daily temperature measurements using a wet-dry bulb thermometer. The daily temperature was measured three times a day (morning at 07.00, afternoon at 13.00, and afternoon at 17.00) from planting to the last harvest.

Seed quality testing was carried out after drying the fruit including moisture content, seed dry weight, germination percentage, dry weight of normal seedling, vigor index, simultaneity of germination, and seedling growth rate.

2.4 Data Analysis

Data were analyzed using Microsoft Excel software and Statistical Analysis System (SAS) 9.1. Analysis of variance was carried out using the F test, and any significant effect at the 5% level was further tested with Duncan Multiple Range Test (DMRT).

3 Results and Discussion

3.1 Phenology of Kangkong

Kangkong seeds began to germinate 1–2 DAP, up to 7 DAP the emergence rate in the field reached 80%. Kangkong started flowering 53 DAP, flower buds began to appear 60 DAP,

Fig. 1. The interval of flower development from bud to flower (DAP = days after planting).

Fig. 2. The flower parts consist of flower stalks (a) petal (b), pistil (c), stamens (d), and sepal (e).

blooming 63 DAP, and withering 64 DAP (Fig. 1). The stalks, petals, pistils, stamens, and sepal. Flowers are located at the end of the flower stalk with a stalk length ranging from 3–9 cm. The color of the flowers is white, and each flower has one petal because the flowers are bell-shaped. The inflorescences are in the form of bunches (sometimes single) so that one inflorescence can have one to five flowers. Each ± 6.00 cm; stalk diameter 0.16 ± 0.14 cm; petal length 4.86 ± 2.70 cm; and petal width 2.65 ± 1.10 cm (Fig. 2). The flower, fruit, and seeds of kangkong are shown in Fig. 3. The phenological study is important to better understand generative growth of a plant and to calculate the appropriate heat unit needed as in our previous studies [7, 11].

3.2 The Effect of Harvest Age on Fruit and Seed Measurements

The shape of the fruit is oval or slightly conical at the fruit tip with a smooth surface. The fruit harvested at 16 DAA and 17 DAA had low weight and continued to increase in weight to a maximum at 22 DAA (0.25 g). After that, the fruit weight slightly decreased. Fruit length reached its maximum at 25 DAA (9.19 mm) but was not significantly different from 24, 26, 29 and 30 DAA. The maximum fruit diameter was produced at 29 DAA (Table 1). This shows that the longer the age of fruit harvest, the fruit has increased

Fig. 3. The flower, fruits and seeds of kangkong (Ipomoea reptans Poir.).

Table 1. Description of Kangkong fruits at harvest ages of 16–30 days after anthesis.

Harvest age (DAA)	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)
16	0.17^{e}	8.09^{e}	6.82^{efg}
17	0.17^{e}	8.25^{de}	6.64^{fg}
18	0.18^{e}	8.34^{de}	6.45^{g}
19	0.19^{de}	8.45^{cde}	6.62^{fg}
20	0.21^{cd}	8.37^{de}	6.42^{g}
21	0.24^{ab}	8.62^{bcd}	6.99defg
22	0.25^{a}	8.66^{bcd}	7.32abcde
23	0.23^{abc}	8.28^{de}	7.55abcd
24	0.22^{abc}	8.85^{abc}	7.07cdef
25	0.23^{abc}	9.19^{a}	7.63^{abc}
26	0.22^{abc}	9.05^{ab}	7.68^{abc}
27	0.23^{abc}	8.13^{e}	7.35abcde
28	0.23^{abc}	8.24^{de}	7.23bcdef
29	0.21^{bcd}	9.27^{a}	7.92^{a}
30	0.22^{abc}	9.18^{a}	7.86^{ab}

Numbers followed by the same letter in the same column show no significant difference at the 5% DMRT test. Fruits were dried in the sun for 3–4 days at 09.00–15.00; DAA = days after anthesis

in length and diameter. This happened because the length and diameter of the fruit had not reached their maximum when physiological maturity. The fruit color was light green and turned brown when it started to dry, the time that the fruit can be harvested.

The seeds of kangkong cv KK02 were light green before drying and dark brown after drying. Changes in seed color can be observed from each harvest age (Table 2). Seeds were short in shape and evenly brown. One fruit had 1–5 seeds, the wider the fruit, the more seeds it had. The seeds increased in length and width of seeds until they reached a maximum at 28 DAA when the length of the seed was 5.72 mm and the width of the seed was 4.33 mm (Table 2). Fruit size affected the size of seeds per fruit but did not affect the number of seeds per fruit. The number of seeds per fruit is also not affected

Table 2. Description of the kangkong seeds at harvest age 16–30 days after anthesis.

Harvest age (DAA)	Seed length (mm)	Seed width (mm)	Seed color (before drying)	Seed color (after drying)
16	5.16ef	4.13bcd	White	Light brown
17	5.04fg	3.96de	White	Light brown
18	5.14ef	3.99de	White	Light brown
19	4.90g	3.84e	White	Light brown
20	5.02fg	3.97de	White	Light brown
21	5.32cde	4.19abc	White	Dark brown
22	5.23de	3.97de	White	Dark brown
23	5.15ef	4.10bcd	White	Dark brown
24	5.33cde	4.08bcd	White	Dark brown
25	5.63ab	4.05cd	White	Dark brown
26	5.65ab	4.26abc	White	Dark brown
27	5.39cd	4.12bcd	White	Dark brown
28	5.72a	4.30a	White	Dark brown
29	5.48bc	4.19abc	White	Darker brown
30	5.62ab	4.24ab	White	Darker brown

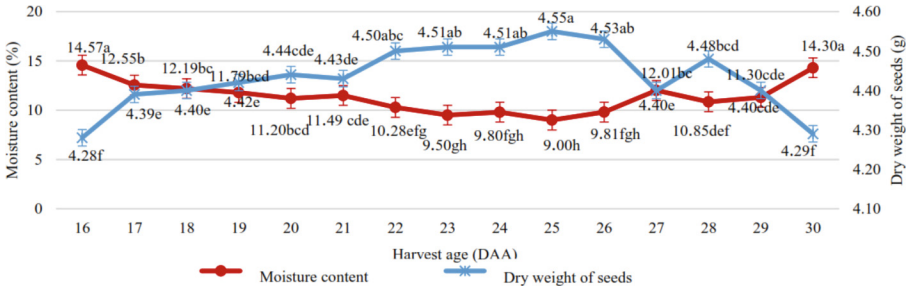
Numbers followed by the same letter in the same column show no significant difference at the 5% DMRT test. Fruits were dried in the sun for 3–4 days at 09.00–15.00; DAA = days after anthesis.

by the harvest age. The average number of seeds at each harvest age is approximately the same, four seeds per fruit.

3.3 Effect of Harvest Age on Moisture Content and Dry Weight of Seed

The water content of kangkong seeds tended to decrease as the harvest age increases. The highest water content at harvest age of 16 DAA was 14.57% and the lowest was 9% at 25 DAA (Fig. 4). The seed moisture content of eggplant (Solanum melongena var. Serpentinum) decreased in line with the increase in fruit maturity [13]. Similarly, the moisture content of cucumber seeds (Cucumis sativus L.) at harvest age 15 days after flowering (DAF) was still very high 70.6% then decreased with increasing the harvest age, and at 29 DAF, the moisture content was down to 41.5% [7]. In Bambara groundnut seeds, the moisture content at 65–75 DAP was still very high (ranging at 70–76%), then decreased at a slow rate until physiologically matured the moisture content was 54–59% [14].

The highest dry weight of kangkong seeds was obtained at the harvest age of 25 DAA (4.55 g), while the lowest was at 16 and 30 DAA (Fig. 4). The seeds of Cosmos caudatus Kunth. Reached physiological maturity at harvest age of 40 days after flowering (DAF) which was characterized by 10% moisture content, viability, vigor, and maximum seed dry weight [15]. Seeds that reach physiological maturity have sufficient food reserves



Numbers followed by the same letter in the same line show no significant difference at the 5% DMRT test. DAA (the day after anthesis)

Fig. 4. The effect of harvest age on moisture content and dry weight of seeds.

and complete embryo formation. The differences in seed maturity influenced the seed viability of three varieties of eggplant [16]. The dry weight of kangkong seeds began to decrease at 27 to 30 DAA due to the increasing seed moisture content at 27 to 30 DAA (Fig. 4). The increase in water content was caused by unfavorable environmental conditions, the harvesting was done after raining so that the water content and humidity were still high and the weather was always cloudy when drying in the sun so that the drying was not optimal and the humidity was high when the fruits were stored at night.

3.4 Effect of Harvest Age on Seed Viability

The seed germination at 16 DAA was the lowest (48.5%) compared to other harvest ages. The germination percentages continued to increase with increasing ages of harvest. At harvest age 21–24 DAA, germination ranged from 75.5 to 79.5%. The highest germination was achieved by the seeds harvested 25–26 DAA (87% and 84%) then decreased sharply from 27 DAA (55.5%) to 30 DAA (60.5%) (Fig. 5). The minimum quality standard for seed germination, as set by the government, is 70% according to the technical guidelines for horticultural seed certification [17].

The eggplant seeds harvested when physiologically matured at 50 DAF had the highest germination percentage of 93.33% because they had sufficient food reserves for embryo growth [18]. The seeds of Cosmos caudatus could germinate at all levels of maturity or harvest age (24, 28, 32, 36, and 40 DAF) but there were differences in germination at each level of maturity due to insufficient availability of food reserves for embryo growth [15]. The physiologically matured cowpea seeds accumulated maximum food reserves so that the field emergence of A1, A4, A5, A7, and A8 accessions were more than 90% [19]. The germination of kangkong seeds harvested at 25–26 DAA were 84–87% because there were many fresh seeds that did not germinate at the time of observation.

The germination of kangkong seeds began to decline at 27 to 30 DAA because many seeds were rotten or dead, and there was an increase in seed moisture content (Figs. 4 and 5). This was caused by unfavorable environmental conditions, the harvesting was carried out after raining so that the water and humidity levels were still high and the weather was always cloudy when drying in the sun so that the drying is not optimal.

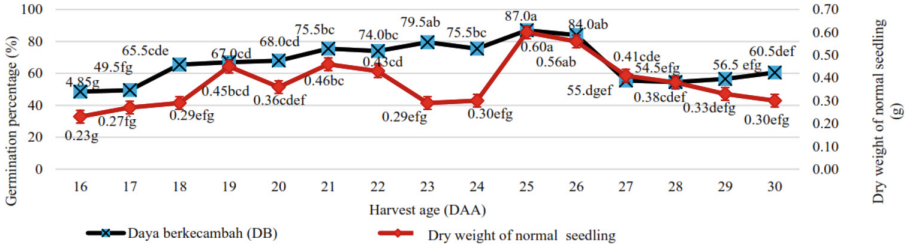


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Fig. 5. The effect of harvest age on germination percentage and dry weight of normal seedling.

The maximum dry weight of normal seedlings (DWNS) was achieved at harvest age of 25 DAA (0.6 g) and not significantly different with 26 DAA (0.56 g). There was a sharp decline in DWNS starting at 27 DAA (Fig. 5), some seeds were rotten (infected by fungus) and then died. The high DWNS at harvest age 25–26 DAA indicates that the availability of food reserves is sufficient so that the germination capacity is high. This is in line with the results on long bean seeds, the seeds that had high germination percentage had a high DWNS [11].

3.5 Effect of Harvest Age on Seed Vigor

The lowest vigor index was at harvest age of 16 DAA (29.5%) and the highest was at 25–26 DAA. Seed vigor index, simultaneity of germination, and seedling growth rate at the harvest ages of 16–22 DAA and 27–30 DAA were lower than the seeds harvested at 23–26 DAA. The seed vigor of 23–26 DAA which was not significantly different proved that the seeds harvested from 23 DAA already had the ability to grow in a sub-optimum environment. All parameters of seed vigor reached their maximum at 25–26 DAA with vigor index of 79% and 83.5%, simultaneity of germination 84% and 83.5% (Fig. 6), and seedling growth rate of 118.11 and 106.83 mg normal seedling-1 (Fig. 7). Seed vigor decreased at 27–30 DAP (Figs. 6 and 7). Our previous work on red bean (Phaseolus vulgaris) seeds showed that the physiological maturity was reached at 36 DAF. Drying methods using the sun and artificial (seed dryer 40 0C) until the moisture content of 9–10% showed maximum seed vigor (simultaneity of 100 germination 81.45%). The seeds that were harvested before reaching physiological maturity resulted in low seed vigor [20]. Similar results on long bean seeds cv Wulung harvested at 21 DAF had a maximum vigor index of 80% and simultaneity of germination 85.5%. The seed vigor of long bean began to decrease after physiological maturity to a vigor index of 69.5% and simultaneity of germination to 77.5% at 23 DAF [11]. In cowpea (Vigna unguiculata L. (Walp.)) seeds cv BRS Guariba, the higher seed vigor at 14–18 DAP coincided with physiological maturity of the seed as indicated by the higher percentage of first count germination (vigor index), longer root and shoot lengths, and increase in dry weight of normal seedlings [21].

The seedling growth rate of kangkong increased 16–26 DAA and then decreased 27–30 DAA (Fig. 7). The maximum seedling growth rate at 25 DAA (Fig. 7) showed that the formation of food reserves was maximum as shown by the highest dry weight

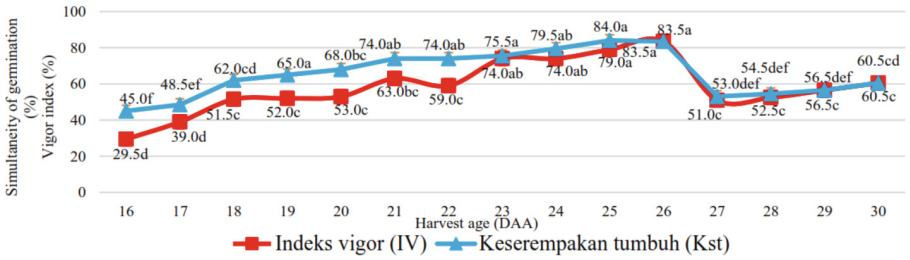

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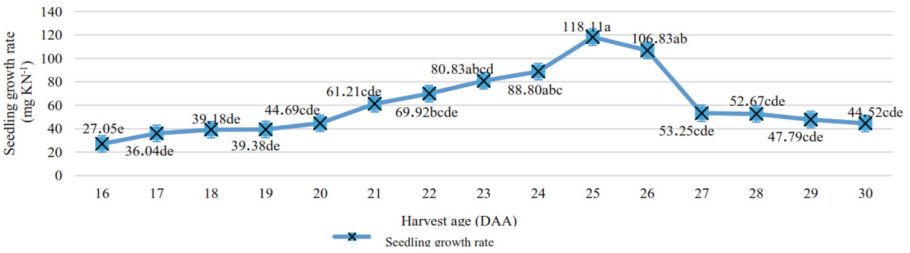
Fig. 6. The effect of harvest age on vigor index and simultaneity of germination.



Numbers followed by the same letter in the same line show no significant difference at the 5% DMRT test. DAA (the day after anthesis)

Fig. 7. The effect of harvest age on seedling growth rate.

of the seeds (Fig. 4). The greater the weight of normal seedling obtained, the greater the ability of the seeds to grow in the field.

3.6 Determination of Physiological Maturity of Kangkong Seeds

Physiological maturity of kangkong seeds was reached at 25 DAA when the seed moisture content was the lowest while seed dry weight, viability, vigor were maximum (Figs. 3, 4, 5, and 6). Physiological maturity is an important growth stage for plants because it is associated with the accumulation of seed dry weight and maximum yield [4]. Research on five local varieties of cowpea from Nigeria showed different times to reach physiological maturity. The period between flowering and physiological maturity influenced the rate of seed filling [22]. Kangkong fruits and seeds harvested at 25–26 DAA were dark brown after being dried (Table 2), this is true according to the description of KK-02 variety. The Ipomoea lacunose seeds reached physiological maturity 22 DAA with dark brown color of the seeds [23].

3.7 Determination of Heat Units

Each plant requires the accumulation of a certain unit of heat to reach a certain stage. Kangkong plants require certain heat units at various growth stages from seedling emergence to physiological maturity (25 DAA). The seedling emergence occurred at 3–4

Table 3. Pigment content in two-winged bean varieties and harvest age.

Stage of growth and development	Heat unit (°Cd)
a) The emergence of seedling	62.75
b) The vegetative phase	870.63
c) The appearance of flower buds	887.63
d) The blooming of flower	1063.00
e) The appearance of fruit	1229.25
f) Physiological maturity (25 DAA)	1668.50

°Cd = degree Celcius day; DAA = days after anthesis; (a) 3 DAP, (b) 52 DAP, (c) 53 DAP, (d) 63 DAP, (e) 73 DAP, (f) 88 DAP; DAP = days after planting.

DAA, with field emergence of 76.75%, required a heat unit of 62.75 °Cd. The vegetative stage lasted up to 52 DAP with an accumulation of heat units of 870.63 °Cd. The flower buds appeared at 53 DAP and bloomed at 63 DAP with accumulated heat units of 1,063.00 °Cd (Table 3). Cucumber (Cucumis sativus L.) plants require a heat unit of 979.8 °Cd to reach physiological maturity at 29 DAF [7]. The time to reach physiological maturity is not always the same depending on the planting location and growing season. The results of [24] showed that the growth cycle of cowpea (starting from sprouting, flowering, and physiological maturity) was shorter in tropical climates than in temperate climates.

4 Conclusion

The physiological maturity of kangkong seeds cv KK02 was reached 25 days after anthesis (DAA) or equivalent to a heat unit of 1.668,50 °Cd, characterized by the brownish color of fruit and dark brown color of seeds after drying. At harvest age of 25 DAA, seed moisture content was the lowest (9%) while seed dry weight (4.55 g), viability (87% germination, and dry weight of normal seedlings 0.6 g), and seed vigor (vigor index 79%, simultaneity of germination 84%, and seedling growth rate of 118.11 mg per normal seedling) reached their maximum. It is suggested that the kangkong seeds are harvested at 25 DAA with a heat unit of 1,668.50 °Cd.

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