Phenological growth stages of longan (*Dimocarpus longan*) according to the BBCH scale

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ABSTRACT

Longan (*Dimocarpus longan*) is an important evergreen fruit crop grown in tropical and subtropical climates, with a clear expanding potential, but with a poorly described phenology. In this work, the different phenological growth stages of longan are characterized according to the BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische industrie) scale. From vegetative bud dormancy to fruit harvest, seven main growth stages are described for bud, leaf and shoot development, inflorescence emergence, flowering, fruit development and fruit maturity. Within them 41 secondary growth stages are described. The BBCH code will be an important tool to assist the development and implementation of longan management protocols and to standardize observations made in different edaphoclimatic and experimental conditions.

Keywords: BBCH code; *Dimocarpus longan*; Sapindaceae; Phenology

1. Introduction

The longan (*Dimocarpus longan* Lour.) is a subtropical fruit tree species native from Southern Asia. The species is a member of the Sapindaceae, a family that includes other fruit crops such as litchi (*Litchi chinensis* Sonn.), rambutan (*Nephelium lappaceum* L.), guarana (*Paullinia cupana* Kunth), Spanish lime (*Melicoccus bijugatus* Jacq.), ackee (*Blighia sapida* KD Koenig), or pulasan (*Nephelium mutabile* Blume).

The longan was first described in 1790 by the Jesuit missionary and botanist Joao de Loureiro (Loureiro, 1790) although it has a documented history of more than 2200 years in China (Huang et al., 2005), based in its excellent nutritive and pharmaceutical potential (Wong, 2000). The genus *Dimocarpus* contains six species of trees and shrubs and *D. longan* has two subspecies and five varieties distinguished mainly by the leaflet structure (Subhadrabandhu and Stern, 2005): *D. longan* ssp. *longan* var. *longan* (the most important for fruit consumption) originally distributed from Myanmar to southern China, south-west India and Sri Lanka; *D. longan* ssp. *longan* var. *longepetiolulatus* originally distributed in southern Vietnam; *D. longan* ssp. *longan* var. *obtusus* originally distributed in Indochina; *D. longan* ssp. *malesianus* var. *malesianus* and *D. longan* ssp. *malesianus* var. *echinatus* originally distributed in northern Borneo and southern Philippines (Loureiro, 1790; Leenhouts, 1971; Wong and Ketsa, 1991; Subhadrabandhu and Stern, 2005). Nowadays, longan is also cultivated in other regions with tropical to temperate climates in China and South-East Asia, Queensland in Australia, and Florida in the United States, but has a further potential in other countries. The main world longan producing countries are China, with about 1.300 million tons in 2010 (Qiu, 2014), Vietnam, with more than 550 million tons in 2012 (Ministry of Agriculture and Rural Development of Vietnam, 2012), and Thailand with more than 500 million tons in 2014 (Buara and Kumcha, 2014).

Longan is an evergreen tree that can grow up to 20 m high forming alternate paripinnate leaves with 6 to 9 opposite leaflets (Subhadrabandhu and Stern, 2005; Wong and Ketsa, 1991). As other evergreen tropical and subtropical trees, longan produces one or more flushes of shoot growth per year (Nakasone and Paull, 1998; Diczbalis, 2002; Paull and Duarte, 2011). Usually the species has one flowering flush per year but some cultivars can produce three in a two year period (Wong, 2000). The longan inflorescences are compound dichasia, terminal, usually leafless, erect, with widely branched panicles 8-60 cm long (Subhadrabandhu and Stern, 2005; Davenport and Stern, 2005). The flowers are unisexual, small, yellow-brown with five petals and appear generally in three waves in the inflorescence with different degrees of overlap among them depending on the cultivars and the environmental conditions: a first wave of male flowers, followed by a wave of female flowers and, finally, a third wave of male flowers. The female flowers have a bicarpellate ovary although usually only one locule will develop into a fruit (Davenport and Stern, 2005). Each inflorescence contains a large number of flowers, approximate 200-1000 functionally female flowers and 1000-4000 functionally male flowers. Usually, the flowers open at night and pollination takes place in the morning by different insects, mainly honeybees (Davenport and Stern, 2005; Pham et al., 2013). The time from flowering to harvest lasts from 4 to 6 months depending on the environmental conditions and the cultivars. After fertilization, usually two fruit abscission waves take place and finally each panicle can carry about 60-80 fruits (Davenport and Stern, 2005). The edible portion of the longan fruit is a fleshy aril (Wong, 2000).

While several studies on production, floral induction, fruit quality and aril composition, have been performed in longan, little information is available on longan phenology. Previous research has studied fruit development and some phenological stages (Nakasone and Paull, 1998; Diczbalis, 2002; Paull and Duarte, 2011), but to have a complete picture additional work and a standardization of the observations are needed. Thus, in this work, we propose to apply the extended BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische industrie) scale system to describe the phenological growth stages of longan contributing to the standardization of phenology studies in this crop.

2. Materials and Methods

Data were collected from 15 years old adult trees of *Dimocarpus longan* ssp. *longan* cultivars ‘Choompoo’, ‘Fuk How’, ‘Biew Kiew’, and ‘DuanYu’, propagated by air layering, located at IHSM la Mayora in Malaga (Spain), at latitude 36^{o}45N, longitude 4^{o}4W and elevation 35m above sea level. The climate data of the last 50 years show a mean annual temperature for this location of 18.5^{o}C, average maximum temperatures of 28.9^{o}C in the hottest month (August) and average minimum temperature of 9.8^{o}C in the coolest month (January), with an average annual rainfall of 536 mm.

Measurements and observations of vegetative and reproductive development were carried out during two annual growing seasons (2012-2014). A total of 82 buds located in 25 branches of 5 trees (5 branches of each) were marked and measurements were made twice or once per week, or twice per month depending on the developmental stage. During the experimental period the average maximum and minimum temperature were 26.7^{o}C and 12.8^{o}C, respectively.

The BBCH scale described in this work for longan uses 7 of the 10 principal growth stages starting with stage 0 (vegetative bud development), followed by stages 1 (leaf development), 3 (shoot development), 5 (inflorescence emergence), 6 (flowering), 7 (development of fruit), and ending with stage 8 (maturity of fruit). Secondary stages are described in detail. As in most fruit trees, principal growth stage 2 (formation of side shoots/tillering), 4 (development of harvestable vegetative plant parts or vegetative propagated organs/booting), and 9 (senescence, beginning of dormancy) are not considered for longan.

3. Results and Discussion

In this work, the phenological growth stages of longan according to the extended BBCH scale are described (Fig. 1), under the environmental conditions of Southern Spain, separating the vegetative and reproductive flushes (Fig. 2). The description is divided in seven main growth stages, three for vegetative growth (including bud, leaf, and shoot development) and four for reproductive development (including inflorescence emergence, flowering, fruit development, and fruit maturity). Within them a total of 41 secondary growth stages were described (Table 1).

111

3.1. Principal growth stage 0: vegetative bud development

The first vegetative buds were apparent usually two to four weeks after harvesting the fruits. This occurred in the winter from December to January and depended on the harvesting time (Fig. 2).

010. Vegetative buds dormant: foliar buds are completely closed and covered by brownish scales (Fig. 1).

011 Beginning of bud swell: bud scales begin to open.

013 End of bud swell: brownish scales are slightly separated (Fig. 1).

017 Beginning of bud break: compound leaf tips start to become visible (Fig. 1).

019 End of bud break: shoot tip is clearly visible and first compound leaves slightly separate (Fig. 1).

Additional flushes: Under climatic conditions where additional vegetative flushes are observed, additional mesostages can be added: 020, 021…

3.2. Principal growth stage 1: leaf development

Most leaves on the first vegetative growth flush emerged in winter, over January and February (Fig. 2). Growth phase 110–119 was completed in approximately 50-60 days.

110. First leaves separated: leaflets of the first compound leaf separating and showing reddish color.

111. First leaves unfolded: All leaflets of the first compound leaf unfolded, first leaflets at 10% of their full size or nearly 10% compound leaves unfolded.

113. More leaves unfolded: First leaflets at 30% of their full size or nearly 30% compound leaves unfolded (Fig. 1).

116. More leaves unfolded: First leaflets at 60% of their full size and changing color from red to red-green or nearly 60% compound leaves unfolded.

119. All leaves unfolded: all leaflets fully expanded, first leaflets nearly at 100% of their full size and changing from red to red-yellow-green (Fig. 1).

Additional flushes: Under climatic conditions where additional vegetative flushes are observed, additional mesostages can be added.

3.3. Principal growth stage 3: shoot development

The vegetative flush normally took place in spring (February/March) before inflorescence emergence (stage 5) and flowering (stage 6) (Fig. 2).

310. Beginning of shoot extension: axes of developing shoots visible. This growth stage proceeds in parallel with stage 110.

311. 10% of final shoot length. This growth stage proceeds in parallel with stage 113 (Fig. 1).

313. 30% of final shoot length. This growth stage proceeds in parallel with stage 116.

315. 50% of final shoot length. This growth stage proceeds in parallel with stage 119 (Fig. 1).

317. 70% of final shoot length: first leaflets changed to light green (Fig. 1).

319. 90% or more of final shoot length: all leaflets changed to light green, shoots completely developed (Fig. 1).

Additional flushes: Under climatic conditions where additional shoot development flushes are observed, additional mesostages can be added.

3.4. Principal growth stage 5: inflorescence emergence

Reproductive bud development occurred during the spring from April to early May (Fig. 2). At the end of this stage, flower bud developed completely. Short ovary, stigma and anthers can be observed under the binocular microscope after removing the petals and sepals (Fig. 2). Detailed anatomical images of different stages during reproductive bud development are provided in Fig. 3).

510. Reproductive buds dormant: completely closed and covered with brownish scales (Fig. 1).

511. Beginning of reproductive bud swell: brownish scales separating and flower buds visible (Fig. 1, Fig. 3).

512. Panicle axes begin to elongate: folded primary leaves are visible in the principal axes (Fig. 3).

513. Beginning of panicle development: primary branches visible, folded leaves clearly visible, usually the leaves will drop but sometimes they can unfold and grow as the compound leaves (Fig. 1, Fig. 3).

515. Inflorescences 50% of final length: secondary branches visible (Fig. 1, Fig. 3)).

517. Inflorescences 70% of final length: secondary branches elongated, tertiary branches visible (Fig. 1, Fig. 3).

519. End of inflorescence extension: tertiary branches almost fully developed; individual flower pedicels elongated, flowers separated and closed, corolla change from brownish to green (Fig. 1, Fig. 3)).

Additional flowering periods: Under climatic conditions where there is more than one flowering period, additional mesostages can be added.

3.5. Principal growth stage 6: flowering

The first flowers opened in mid spring in May and flowering continues for about 35-45 days in the same individual tree (Pham et al., 2013) (Fig. 2).

Similar to litchi, longan has three types of flowers (Davenport and Stern, 2005): staminate flowers (M1), functionally female hermaphrodite flowers (F), and functionally male hermaphrodite flowers (M2). It has been put forward that three waves of longan flowers are present in the inflorescences. The first wave consists of M1 flowers, the second of F flowers, and the third of M2 flowers (Davenport and Stern, 2005; Paull and Duarte, 2011; Jonathan, 2013), although climatic conditions or cultural management practices may modify this pattern (Paull and Duarte, 2011). Also there is an overlap of the different flower types in the same tree since not all the panicles are in the same developmental stage.

610. First flowers open: female (F) or male (M1) flowers open depending on tree and climate conditions (Fig. 1).

611. Beginning of flowering: 10% flowers open.

613. Early flowering: 30% flowers open (Fig. 1).

615. Mid bloom: 50% flowers open, both female (F) and male (M2) flowers can be found at this time (Fig. 1).

617. Full flowering: 70% flowers open, some initial fruit set can be found (Fig. 1).

619. End of flowering: 90% flowers open, most petals dried out and dropped, numerous fruits have already set (Fig. 1).

Additional flowering periods: Under climatic conditions where there is more than one period of flowering, additional mesostages can be added.

3.6. *Principal growth stage 7: fruit development*

Longan fruit growth took place during 4 months from June/July to October/November (Fig. 2). Longan fruit development could be divided into two main growth stages (Ke et al., 1992; Zheng et al., 1994; Chen et al., 1995; Xu et al., 1997). In the first stage, pericarp and aril development started and the seed coat, embryo and endosperm can be observed with the naked eye. This stage occurred 1-50 days after anthesis. The second stage is characterized by the embryo filling the seed cavity, hardening of the seed coat, thinning of the pericarp, development of the fleshy aril and the maturation process (Fig. 2). Detailed images of some of those steps are provided in Fig. 4).

Zee et al. (1998) reported two waves of fruit abscission in longan in China. The first cycle occurred 3–20 days after fertilization, and the second 30–60 days before harvest. In southern Spain, the first fruit abscission takes place 1-6 weeks after anthesis. At harvest time, each panicle can carry about 60-80 fruits (Davenport and Stern, 2005) although about 1000 female flowers can be produced per panicle.

710. No ovary growth still visible

711. Initial ovary growth, following fertilization. First physiological fruit abscission (Fig. 1).

712. 20% of final fruit size. Beginning of ovary growth: one (two) ovary carpel(s) dried, one fertilized ovary carpel growing: (Fig. 1, Fig. 4).

713. 30% of final fruit size, fruits show muricate skin (Fig. 1).

715. 50% of final fruit size: skin is still muricate, and the seed is covered by the aril (Fig. 1, Fig. 4).

717. 70% of final fruit size: skin changes from muricate to rough and the aril becomes fleshy (Fig. 1).

718. 80% of final fruit size (Fig. 1, Fig. 4).

719. 90% or more of final fruit size (Fig. 1).

Additional fruiting periods: Under climatic conditions where there is more than one period of flowering and fruiting, additional mesostages can be added.

3.7. Principal growth stage 8: fruit maturity

Fruit maturation took place at the end of the autumn, in November/December, depending on the year and the cultivar (Fig. 2). During this stage, the fruit is still growing. The fruits are ready for harvest when the pericarp is thin, smooth, tough and leathery, and its color changes from green-yellow to yellow-brown (Subhadrabandhu and Stern, 2005) (Fig. 2).

810. Physiological maturity: skin is more or less rough, skin color changes from green to light yellow-green; this growth stage proceeded parallel with stage 718 (Fig. 1).

811. Beginning of fruit ripening: fruit skin color changes from light yellow-green to bright yellow, surface skin changes from rough to smooth (Fig. 1); this growth stage proceeded parallel with stage 719.

815. Advanced ripening: fruit becomes smoother with yellow skin color (Fig. 4).

819. Fruit fully ripened, ready for consumption: fruit skin color fully changes to yellow-brown, the fruit is completely smooth, with 100% of final size and ready for harvest (Fig. 1).

While this is the general pattern, in southern Spain two additional vegetative flushes can take place depending on the reproductive flush and the flowering stages. The first additional flush appears if no inflorescences are produced in the branches. This flush occurs at the same time of the normal reproductive growth stage, in mid-spring to early summer, from April to June. A similar situation has been reported in Australia (Diczbalis, 2002). A second additional flush can occur if all flowers, inflorescences or developing fruitlets fall down due to adverse weather conditions or lack of pollination. This flush occurs in mid-summer to early autumn during July and September. These additional flushes can be added as, additional mesostages: 020, 021, 023, 027, 029; 030, 031, 033, 037, 039. Likewise under climatic conditions where there is more than one period of flowering, additional mesostages can be added.

Considerable variation occurs when comparing times of flowering and fruiting in different parts of the world. Flowering in this work spanned from May-June, but in China, flowering takes place from late February to early April (Wong, 2000), in Thailand from late December to late February (Wong, 2000; Stern, 2005), in Queensland from August to October and October to November, depending on the location (Wong, 2000), in Florida in February/March through April and the beginning of May (Jonathan et al., 2013), and in northern Vietnam from the end of March to the beginning of April (Pham et al., 2013). The same applies for fruit maturity that in our conditions occurred in November-December, in China in July-September (Groff, 1921; Wong, 2000), in Thailand in June-August (Stern, 2005; Wong, 2000), in Queensland from January/February to March/April (Stern, 2005; Wong, 2000), in Florida in August-September (Jonathan et al., 2013), and in northern Vietnam from July to August (FAO, 2004). This variability provides a wide fresh fruit provision around the world, but makes difficult to envisage the phenology calendar for a new growing area. To provide a base line, the phenology recorded here is related to temperature (Fig. 2) showing the different temperature requirements for the different major phenology events. Thus, while vegetative growth proceeded between 12-15ºC, flowering occurred between 15-20ºC and fruit development was concomitant with the higher temperatures of 20-27ºC.

In this work, the phenological stages in longan have been described for the first time according to an extended BBCH scale separating the different vegetative and reproductive flushes (Fig. 2). The description here presented will be useful not only to provide basic information on crop requirements, disease and pest management and control but also to facilitate exchange of scientific information among longan experiments performed under different edaphoclimatic conditions.

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Tables

Table 1. Description of the phenological growth stages of longan (*Dimocarpus longan* Lour.) according to the BBCH scale

BBCH code	Description
Principal growth stage 0: vegetative bud development	
010	Vegetative buds dormant
011	Beginning of bud swell
013	End of bud swell
017	Beginning of bud break
019	End of bud break
Principal growth stage 1: leaf development	
110	First leaves separated
111	First leaves unfolded
113	More leaves unfolded: First leaflets at 30% of its full size
116	More leaves unfolded: First leaflets at 60% of its full size
119	All leaves unfolded: all leaflets fully expanded
Principal growth stage 3: shoot development	
310	Beginning of shoot extension
311	10% of final shoot length
313	30% of final shoot length
315	50% of final shoot length
317	70% of final shoot length
319	90% or more of final shoot length
Principal growth stage 5: inflorescence emergence	
510	Reproductive buds dormant
511	Beginning of reproductive bud swell
512	Panicle axes begin to elongate
513	Beginning of panicle development
515	Inflorescences 50% of final length
517	Inflorescences 70% of final length
519	End of inflorescence extension
Principal growth stage 6: flowering	
610	First flowers open
611	10% flowers open.
613	30% flowers open
615	50% flowers open
617	70% flowers open
619	90% flowers open
Principal growth stage 7: fruit development	
710	No ovary growth still visible
711	Initial ovary growth. First physiological fruit abscission
712	20% of final fruit size
713	30% of final fruit size
715	50% of final fruit size
717	70% of final fruit size
718	80% of final fruit size
719	90% or more of final fruit size
Principal growth stage 8: maturity of fruit	
810	Physiological maturity
811	Beginning of fruit ripening
815	Advanced ripening
819	Fruit fully ripened

Figures

Fig. 1. Main phenological growth stages of longan according to the extended BBCH scale

Fig. 2. Progression of longan principal growth stages (PGS) and average monthly temperatures following the BBCH scale in southern Spain.

Fig. 3. Longan flower bud development according to the extended BBCH scale

Fig. 4. Longan fruit development according to the extended BBCH scale

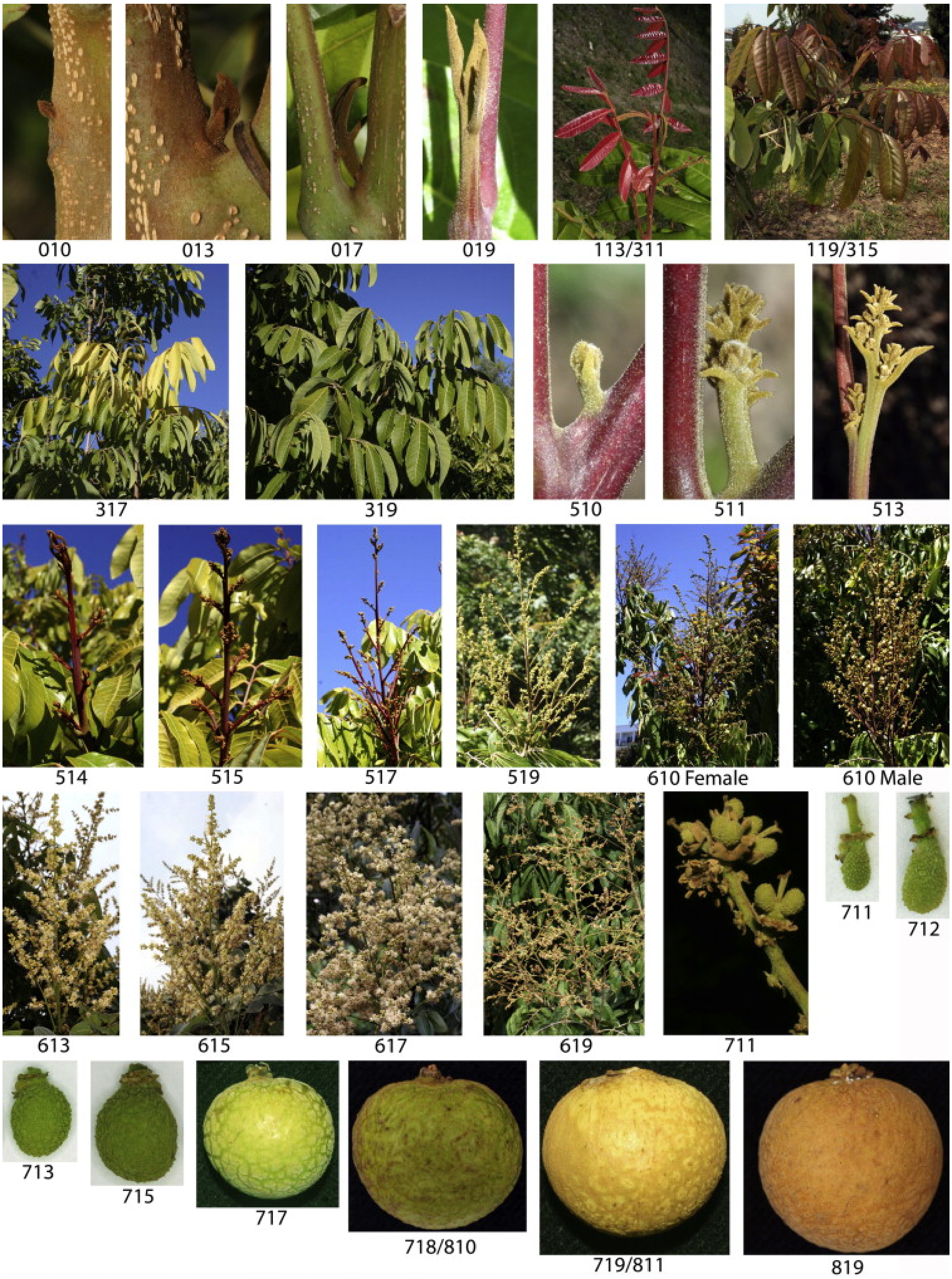

010
013
017
019
113/311
119/315
317
319
510
511
513
514
515
517
519
610 Female
610 Male
613
615
617
619
711
711
712
713
715
717
718/810
719/811
819

Fig. 1

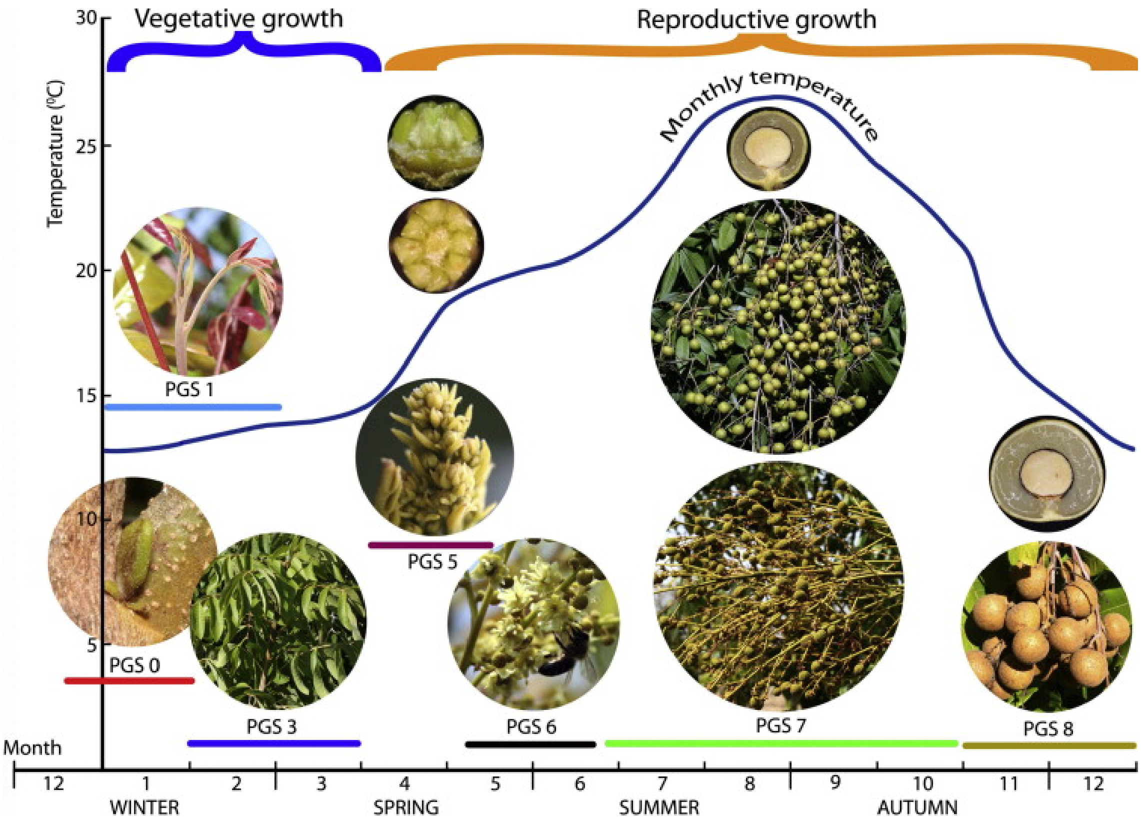
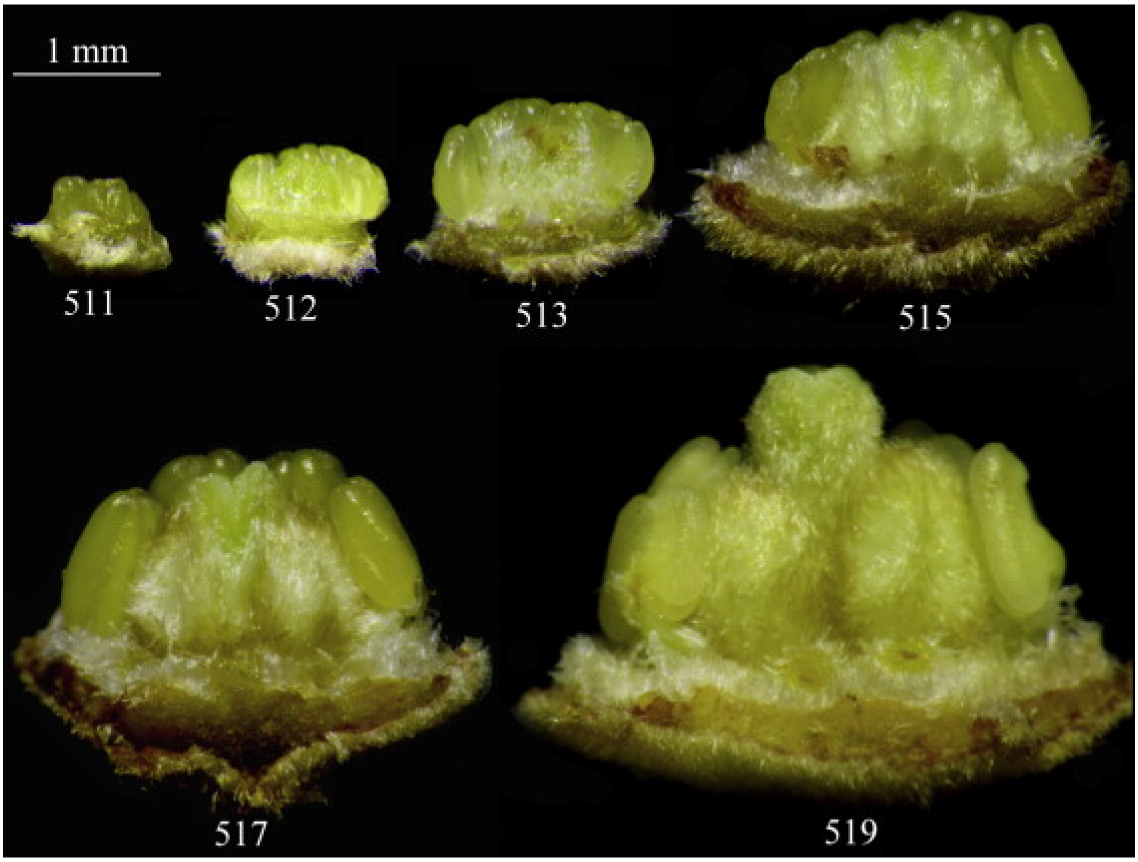
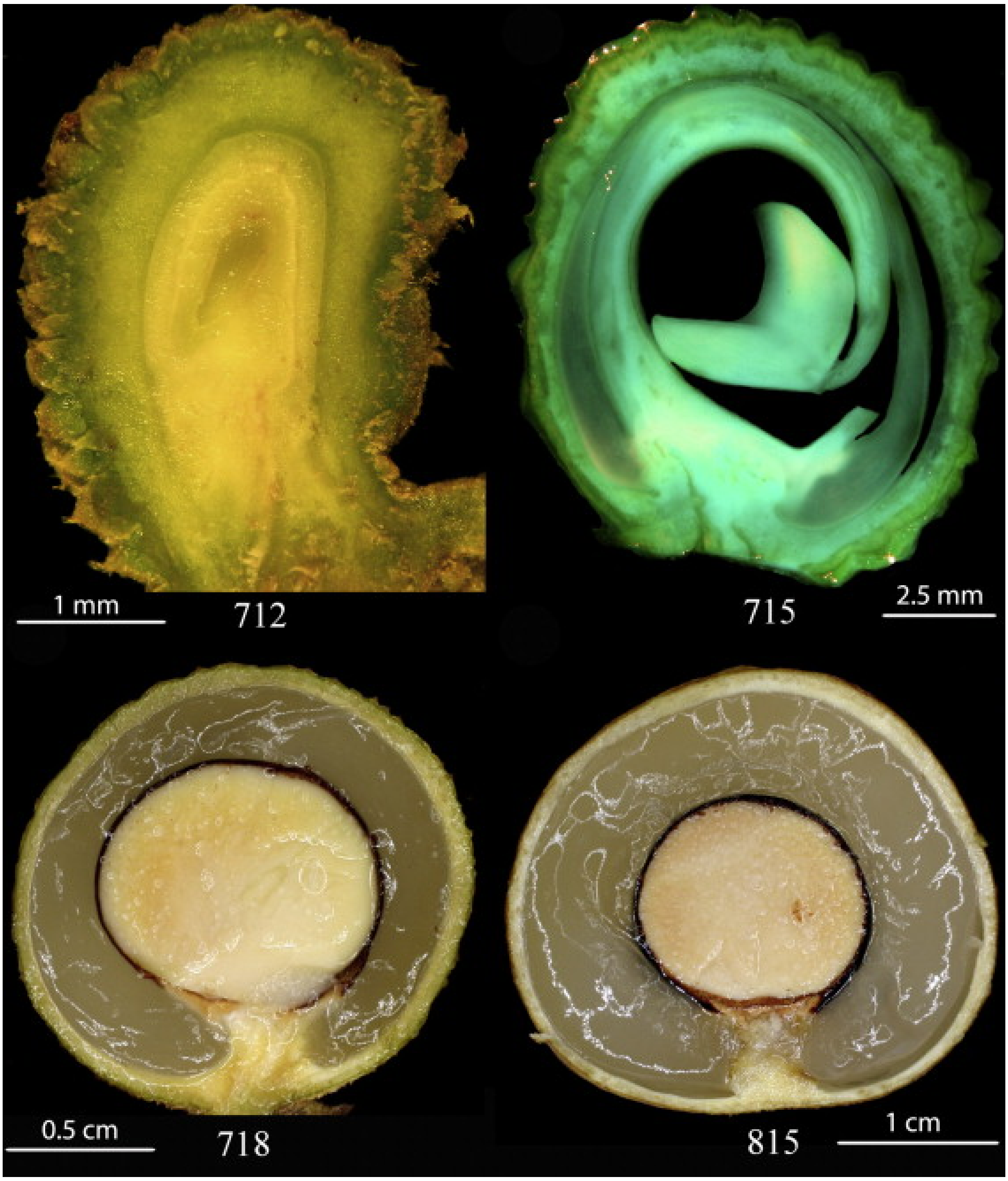

Vegetative growth
Reproductive growth
Monthly temperature
Temperature (ºC)
30
25
20
15
10
5
PGS 0
PGS 1
PGS 3
PGS 5
PGS 6
PGS 7
PGS 8
Month
12
1
2
3
4
5
6
7
8
9
10
11
12
WINTER
SPRING
SUMMER
AUTUMN

Fig. 2

389 

390 Fig. 3



391

392 Fig. 4