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RESEARCH ARTICLE

Phenological growth stages of jackfruit (*Artocarpus heterophyllus*) according to the extended BBCH scale

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Abstract

Jackfruit, the largest known edible fruit bearing tree, is one of the important fruit crops of India. It exhibits wide range of diversity with respect to fruit character and bulb quality. It is an important component of homestead garden because of its multifarious uses (dessert, vegetable and pickle) and high nutritive value. In spite of high food value and market potential, jackfruit is one of the poorly researched crops and there is a dearth of information about its phenology. The present study defines phenological stages of jackfruit according to the extended BBCH (Biologische Bundesantalt, Bundessortenamt und Chemische Industrie) scale using three-digit numerical system. Eight principal growth stages, namely bud development (stage 0), shoot development (stage 1), leaf development (stage 3), specialised reproductive shoot development (stage 4), reproductive development (stage 5), flowering (stage 6), fruit development (stage 7) and fruit maturation (stage 8) have been described. A total of 42 secondary growth stages have been described and defined. In this study, bearing and non-bearing footstalks as well as male and female phases have been defined separately. The study will act as an effective tool for providing a consensual unified approach for standardisation of phenophases, as well as for efficient orchard management for ensuring higher yield and fruit quality. The scale may also be effectively used for characterisation and adaptation of germplasm and assessment of climatic impact on crop phenology.

Introduction

Jackfruit (*Artocarpus heterophyllus* Lam., Syn., *Artocarpous integrifolia* L.), the largest known edible fruit bearing tree species, is one of the important crops of the tropics and subtropics of southeast Asia. It is native to India and is believed to have originated in the rainforest of Western Ghats. Apart from India, it is also cultivated in Bangladesh, Myanmar, Malaysia, Nepal, Thailand, Vietnam, China, Philippines, Indonesia and Sri Lanka. Jackfruit is also found in Latin American and East African countries. Except temperate region, jackfruit is found throughout India and it is known by various vernacular names like *kathal*, *kantaka*, *panasa*, *jak* and *jaca*. India is blessed with wide jackfruit diversity with regard to its maturity, fruit shape, fruit size, spine character, latex, flake size, flake colour, flake texture, taste and sweetness (Jagadeesh *et al.,* 2007; Khan *et al.,* 2010; Sindhu, 2012). Jackfruit belongs to the family Moraceae which comprises of 40 genera and more than 1200 species (Anon, 2013). Among them, *A. heterophyllus* is the most important species. Other economically important species are *Artocarpus altilis* (breadfruit), *Artocarpus lacucha* (monkey jack, barhal), *Artocarpus integer* (champadak), *Artocarpus odoratissimus* (marang), *Artocarpus lanceaefolius* (kledang) and *Artocarpus rigidus* (mandalika) (Elevitch & Manner, 2006; Haq, 2006). Cytogenetically, jackfruit is a tetraploid species with a somatic chromosome number of 56 ($2n = 4x = 56$) and a basic chromosome number of 14.

Jackfruit is a medium-sized tree bearing large fruits (may reach up to 50 kg) on trunk and old branches signifying its cauliflory nature. It is primarily used as dessert (ripe) and vegetable (unripe) but it is also used for fodder, timber, fuel, and medicinal and industrial products. In ripe fruit, fleshy aril (flake) is the edible part but seeds are also consumed as vegetable. In addition, flakes and seeds are used for preparation of various processed products considering their nutritional properties. Jackfruit is not only a rich source of carbohydrate, protein, potassium, calcium and vitamins but also possesses antioxidative and medicinal properties. As a result of its high nutritive value, it is called as 'Poor man's food' in southeast Asian countries (Dembinska-Kiec *et al.,* 2008; Jagtap *et al.,* 2010; Swami *et al.,* 2012).

Jackfruit is an evergreen tree characterised by its dense foliage and exudation of latex from above ground plant parts including fruits when injured. It is a monoecious species bearing male and female inflorescence (spike) separately. Jackfruit has a unique character of producing specialised reproductive shoots (footstalks) from main trunk and from older branches thus exhibiting cauliflory nature. Female spikes are produced only on footstalks, whereas male spikes are produced on footstalks as well as on young branches of tree. Male spikes are dull green, relatively elongated and have long peduncle, whereas female spikes are green, stout and granular with short peduncle. In jackfruit, male spikes appear before female spikes. However, their ratios vary with tree age, germplasm and climatic conditions. Female spikes bear hundreds of small sessile flowers with fleshy receptacles. Each flower is characterised by a perianth, stigma and unilocular ovary. Male spikes also bear hundreds of small sessile flowers with single stamens. Unlike female spikes, male spikes do not grow continuously and start decaying with the completion of pollen dehiscence. Jackfruit produces a multiple fruit (syncarp) with a green to yellow-brown exterior rind containing hexagonal bluntly conical carpel apices (spines). Perianth of the individual flowers becomes the fleshy pericarp and surrounds the seeds, each pericarp and seed being an individual fruit. The fleshy aril along with the seed is called bulb which varies in number, size, colour, texture and chemical properties. The fruit axis is the modified mature inflorescence axis and is somewhat dome-shaped, rigid and slightly fleshy (Pushpakumara, 2006). In India, ripe jackfruits are available mainly during June to August.

Plant phenology, the study of recurring events in the life cycle of plants, has gained increasing scientific attention over the last few decades because of its sensitivity to seasonal and climatic change and its consequences on crop production (Tang *et al.,* 2016). Phenological events are intimately linked to specific developmental phases (phenophases) of plant species such as bud initiation, shoot development, flowering, fruit development, fruit maturation, dormancy, etc. These stages are described by the BBCH (Biologische Bundesantalt, Bundessortenamt und Chemische Industrie) numerical scale, a system for uniform coding of growth stages (Meier, 2001). The basic BBCH scale, represented by two digits, deals with the primary and secondary scales and each scale is subdivided into 10 (0–9) clearly recognisable and distinguishable developmental phases. The primary scale describes the principal stages associated with the developmental cycle of the plants, whereas the secondary scale is a subsequent division of the principal stages into 10 developmental stages (Bleiholder *et al.,* 1989). The extended BBCH scale, a three-digit scale, provides more detailed description about crop by considering mesostages (1–*n*), which are incorporated between the primary and secondary stages (Hack *et al.,* 1992). Both scales (simple and extended) have been widely used to describe phenological stages of fruit crops (Fadon *et al.,* 2015; Hernández *et al.,* 2015; Liu *et al.,* 2015; Shi *et al.,* 2015; Kishore, 2016; Martínez-Nicolás *et al.,* 2016; Zhang *et al.,* 2016). The precise and standardised description of phenological stages is essential for effective crop management practices, characterisation and conservation of germplasm and breeding programme (Kishore *et al.,* 2017). Moreover, characterisation of phenological stages such as bud development, reproductive development, fruit development and fruit maturation is essential to achieve higher yield and better fruit quality as important agronomical practices like nutrient management, pest management, disease management, etc. rely on the recognition of specific phenological stages. Because the phenology of jackfruit has not yet been described, the aims of the study are to define phenological growth stages according to the extended BBCH scale and to enable the growers for efficient crop management practices in order to ensure higher crop yield and facilitate researchers for germplasm characterisation and effective implementation of breeding programme.

Materials and methods

Studies were conducted at the Central Horticultural Experiment Station (ICAR-IIHR), Bhubaneswar (elevation: 45 m amsl; latitude: 20°27′N; longitude: 85°40′E) located in the eastern coastal region of India. The region experiences tropical hot and humid climate with annual rainfall of 1550 mm, mean annual temperature of 27.4°C, average maximum temperatures of 33.7°C, average minimum temperature of 22.2°C and average relative humidity of 76.5%. The climate of the region is characterised by relatively long spell of rainfall (June–September) and summer (February–May), and brief spell of mild winter (December–January). Data on vegetative and reproductive phases at different developmental stages were collected from 10 to 12-year-old plants of 10 jackfruit germplasm during two annual growing seasons (2015–2016; 2016–2017). Data on various phenological stages of bud development and reproductive development were recorded weekly, whereas development of shoot and fruit were recorded twice per month from 160 tagged branches located in 20 randomly selected trees (two trees from each germplasm). The proposed extended BBCH phenological scale for jackfruit is represented by eight principal growth stages starting with stage 0 (vegetative development) followed by stages 1 (leaf development), 3 (shoot development), 4 (development of specialised reproductive shoots), 5 (reproductive development), 6 (flowering), 7 (fruit development) and 8 (fruit maturity). The stage 2 (formation of side shoots) and stage 9 (senescence) are not described because they are not applicable in jackfruit. Principal growth stages were further divided into 10 secondary stages (0–9) corresponding to intermediate developmental stages linked to specific stage. These stages represent either qualitatively different stages or percentage values of growth within a given principal growth stages. Mesostages (1, 2, 3, …, $n-1$, n) were used to define the frequency of occurrence of principal growth stages during a crop cycle. For example, the code 715 represents fruit development stage at first flush when syncarp attains about 50% of final size. Because jackfruit is a heterogamous monoecious plant wherein male and female inflorescences (spikes) are borne separately, stage 5 and 6 have been described separately for male and female spikes. Similarly, the two different forms of stage 4 (bearing and non-bearing footstalks) have also been defined separately. The phenological growth stages and flower development were sequentially characterised and photographed. In order to characterise development of reproductive parts, male and female spikes were collected at different stages during December–January and photographed under a stereoscopic microscope (Leica S8 APO, Wetzlar, Germany).

Results

Phenological growth stages of jackfruit represent different developmental stages occurring annually, starting with bud development and ending with fruit maturation (Table 1). The principal growth phases of jackfruit are divided into eight stages; four for vegetative growth (bud, leaf, shoot development and footstalk development) and four for reproductive growth (inflorescence emergence, flowering, fruit development and fruit maturation). There is no dormant stage (senescence) in jackfruit because of its evergreen nature. Within principal growth stages a total of 42 secondary growth stages are described (Table 1). For simplification, under each principal growth stage of jackfruit one mesostage is taken into account which represents first flush of principal growth stages (1). However, on the basis of frequency of occurrence (flush) of principal growth stages in a crop cycle mesostages may be considered. For example, the first secondary stage (1) of bud development (0) at first flush (1) of jackfruit is represented by 011, whereas 021 represents first secondary stage (1) of bud development (0) at second flush (2). Similarly, codification of different growth stages (0–9) at different mesostages (1–n) may be performed.

1. Principal growth stage 0: bud development (mesostage 1)

Development of vegetative buds in jackfruit occurred in 4–5 flushes (mesostages). However, the maximum number of flushes (3) was observed during June–September. Buds pass through different developmental phases and finally transform into leaves.

011. Beginning of bud elongation: bud light green in colour, bud closed (Fig. 1).

013. Beginning of bud swelling: buds enlarged (Fig. 1).

015. Advanced bud swelling: bract colour turned light yellow (Fig. 1).

017. Beginning of bud break: bracts start separating, bud elongation continues (Fig. 1).

019. End of bud break: green leaf tips visible, leaves start emerging (Fig. 1).

Additional mesostages (2, 3, …, n) may be added as per the occurrence of flushes for bud development.

2. Principal growth stage 1: leaf development (mesostage 1)

Leaves are simple, dark green, medium size, alternate, leathery and elliptical to oval in shape. They are often deeply lobed at juvenile stage. The flushes of leaf emergence are in tandem with shoot growth.

110. First leaves separating: leaves emerging, bracts separated (Fig. 1).

111. Lamina starts unfolding: more leaves start separating, bracts start fading (Fig. 1).

113. Leaves unfolded: first leaves 20% of final size, leaves light green in colour, bracts dehisced (Fig. 1).

115. Leaves unfolded: first leaves 50% of final size (Fig. 1).

117. More leaves unfolded: first leaves 70% of full size, leaves turned green (Fig. 1).

119. All leaves unfolded: leaves attain full size, leaves turned dark green (Fig. 1).

Additional mesostages (2, 3, …, n) may be added as per the occurrence of flushes for leaf development.

3. Principal growth stage 3: shoot development (mesostage 1)

Shoot development in jackfruit is a continuous process because of its evergreen mature. However, July to September was the most favourable period for growth. Shoots emerge in different flushes during a year. Under

Table 1 Description of the phenological growth stages of jackfruit (*Artocarpus heterophyllus*) according to the extended BBCH scale

BBCH code	Description (mesostage 1)
Principal growth stage 0: vegetative bud development	
011	Beginning of bud swelling
013	Advanced bud swelling
015	End of bud swelling
017	Beginning of bud break
019	End of bud break
Principal growth stage 1: leaf development	
110	First leaf emerging
111	First leaf unfolding
113	First leaf unfolded
115	Leaves more than 50% of their full size
117	Leaves more than 80% of their full size
119	All leaves fully expanded
Principal growth stage 3: shoot development	
311	Beginning of shoot extension
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 4: development of specialised non-bearing reproductive shoots (footstalks)	
411 A	Beginning of non-bearing footstalk growth
413 A	30% of final footstalk length
415 A	50% of final footstalk length
417 A	Appearance of first reproductive bud
419 A	Maturation of footstalk and development of reproductive buds
Principal growth stage 4: development of specialised bearing reproductive shoots (footstalks)	
411 B	Beginning of bearing footstalk growth
413 B	30% of final footstalk length
415 B	50% of final footstalk length
417 B	Appearance of first reproductive bud
419 B	Maturation of footstalk and development of reproductive buds
Principal growth stage 5: reproductive development of male bud	
511 A	Beginning of bud swelling
513 A	Beginning of bud development
515 A	Bracts separating
517 A	Advanced bract separation
519 A	End of bract separation and male spike visible
Principal growth stage 5: reproductive development of female bud	
511 B	Beginning of bud swelling
513 B	Beginning of bud development
515 B	Bracts separating
517 B	Advanced bract separation and female spike partially visible
519 B	End of bract separation and female spike completely visible
Principal growth stage 6: flowering (male phase)	
610 A	Beginning of male spike developing
611 A	Beginning of male spike maturation
613 A	Advanced maturation of spike
615 A	Pollen dehiscence started
617 A	Pollen dehiscence completed, end of flowering
619 A	Beginning of spike decay
Principal growth stage 6: flowering (female phase)	
610 B	Beginning of female spike developing
611 B	Beginning of female spike maturation
613 B	Advanced maturation of female spike
615 B	Spike at peak stigma receptivity stage
617 B	Pollination completed
619 B	Fruit set
Principal growth stage 7: Fruit development	
710	Syncarp begins to swell
711	Syncarp growing
713	30% of final fruit size
715	50% of final fruit size
717	70% of final fruit size
719	90% of final fruit size
Principal growth stage 8: fruit maturation	
811	Beginning of fruit maturation
815	Advanced fruit maturation
817	Fruit fully mature for picking
819	Fruit over mature

the tropical climatic condition shoot emerges in 4–5 flushes (mesostages).

311. Beginning of shoot extension: axes of developing shoot visible (Fig. 1).

313. Shoots about 30% of final length: leaf development continues (Fig. 1).

315. Shoots about 50% of final length: basal leaves dark green in colour (Fig. 1).

317. Shoots about 70% of final length: all leaves unfolded, majority of leaves are fully developed (Fig. 1).

319. Shoots about 90% of final length: leaves turned dark green, shoots completely developed (Fig. 1).

Additional mesostages (2, 3, …, n) may be added as per the occurrence of flushes for shoot development.

4. Principal growth stage 4: development of specialised reproductive shoots (footstalks)

Jackfruit exhibits unique character of producing specialised reproductive shoots called footstalks which emerge on the trunk and old branches during the reproductive phase (November–January). There were two types of footstalks – bearing and non-bearing. Bearing footstalks produced both male and female spikes, whereas non-bearing footstalks produce only male spikes. The number of bearing and non-bearing footstalks varied with the germplasm. Bearing footstalks are more vigorous than non-bearing footstalks. It was also observed that the non-bearing footstalks appeared earlier than bearing ones. Footstalks usually start producing reproductive buds after 4–6 weeks of their initiation.

6.1. Development of non-bearing footstalk (mesostage 1)

4.1. Beginning of bud elongation: first leaves emerging (Fig. 1).

Figure 1 Illustrations of the important phenological growth stages of jackfruit (*Artocarpus heterophyllus*) according to the extended BBCH scale.

413 A. Advanced bud elongation: more leaves developed; footstalk still in vegetative phase (Fig. 1).

415 A. Beginning of reproductive phase: reproductive bud appeared (Fig. 1).

417 A. First male spike appeared: development of reproductive bud continued (Fig. 1).

419 A. First male spike matured: more number of male spikes and buds appeared (Fig. 1).

4.2. Development of bearing footstalk (mesostage 1)

411 B. Beginning of bud elongation: first leaves emerged (Fig. 1).

413 B. Beginning of reproductive phase: reproductive buds appeared (Fig. 1).

415 B. First female/male spike appeared: development of reproductive bud continued (Fig. 1).

417 B. Maturation of first female/male spike: development of reproductive bud continued (Fig. 1).

419 B. Maturation of more female and male spikes: more number of female and male spikes appeared (Fig. 1).

Additional mesostages (2, 3, …, *n*) may be added as per the occurrence of flushes for inflorescence development.

5. Principal growth stage 5: reproductive development or inflorescence emergence

Jackfruit is a heterogamous monoecious plant wherein male and female inflorescences (spikes) are borne separately on specialised reproductive shoots. However, male spikes are also borne on normal shoots. The size of buds varies with the type of spike. Male buds are usually elongated and smaller in size, whereas female buds are larger in size. The process of bud development continues for 4–5 weeks. It was observed that the buds of bearing footstalks enclosed spike of either of the sex form and a developing bud which in turn produced spike (male or female) and a new bud. The development phases of male and female buds are described separately for better understanding.

5.1. Development of male buds (mesostage 1)

511 A. Elongation of male buds: buds closed (Fig. 1).

513 A. Beginning of bud development: differentiation of spike and nascent bud initiated, bud shape changed perceptibly (Fig. 1).

515 A. End of bud extension: spathe starts separating, male spike and bud partially visible, spathe starts turning light yellow (Fig. 1).

517 A. Advanced bud opening: male spike and bud clearly visible, spathe turned light yellow (Fig. 1).

519 A. End of bud development: male spike and bud separated (Fig. 1).

5.2. Development of female buds (mesostage 1)

511 B. Elongation of female buds: buds closed (Fig. 1).

513 B. Beginning of bud development: female spike and new bud differentiated (Fig. 1).

515 B. End of bud extension: spathe starts separating, female spike and fresh bud partially visible, spathe starts turning light yellow (Fig. 1).

517 B. Advanced bud opening: female spike and fresh bud clearly visible, spathe turned light yellow (Fig. 1).

519 B. End of bud development: female spike and bud separated.

Additional mesostages (2, 3, …, *n*) may be added as per the occurrence of flushes for inflorescence development.

6. Principal growth stage 6: flowering (male and female phases)

Initial reproductive phase of jackfruit is dominated by male phase which signifies its protandrous nature. Male spikes are elongated, smooth and attached with long and thin peduncle. The initial colour and size of male spikes depend on their origin. Spikes borne on normal shoots are invariably small and light yellow, whereas they are large and light green when appearing on footstalks. Male spikes are densely covered with numerous fertile and sterile staminate flowers. Each flower had a single stamen with a filament, and a bilocular anther. Pollen dehiscence signifies maturity of male spike and end of male phase which is followed by spike decay. The cycle of male phase usually completes in 2 weeks. On the other hand, female spikes emerge late in the season on the bearing footstalks. They are stout, large and granular in appearance and attached with stout peduncle. Numerous female flowers develop on the surface of female spike which are borne on fleshy receptacles. Female flowers are characterised by tubular perianths, ligulate style, papillate fleshy stigma and a unilocular ovary. During the process of development, stigmas emerge throughout the surface of spike which signifies peak stigma receptivity which is followed by fruit set and initiation of syncarp development. Female phase completes in about 4 weeks.

6.1. Development of male spike (mesostage 1)

610 A. Beginning of spike development: spike completely separated, spathes start fading (Fig. 1).

611 A. Advanced spike development: spike attained 50% of final length; spathes dehisced, differentiation of staminate flowers initiated (Fig. 1).

613 A. End of spike development: spike attained full size, staminate flower differentiated, beginning of anthesis (Fig. 1).

615 A. Full bloom: most of the male flowers open, most of the anthers dehisced (Fig. 1).

617 A. Beginning of spike fading: spikes start decaying (Fig. 1).

619 A. Advanced spike decay: completion of male phase (Fig. 1).

Additional mesostages (2, 3, …, *n*) may be added as per the occurrence of flowering flushes.

6.2. Development of female spike (mesostage 1)

610 B. Beginning of spike development: spike completely separated from bracts, fading of spathes begins (Fig. 1).

611 B. Advanced spike development: spike attained 30% of final size, spathes dehisced, differentiation of pistillate flowers initiated (Fig. 1).

613 B. Beginning of spike maturation: spike attained 50% of final size, beginning of anthesis, stigmas start emerging (Fig. 1).

615 B. Advance maturation: spikes completely covered with milky white stigmas, peak stigma receptivity (Fig. 1).

617 B. Beginning of fruit set: pollination completed, fading of stigma started (Fig. 1).

619 B. Advanced fruit set: fading of stigma completed, completion of female phase, beginning of syncarp development (Fig. 1).

7. Principal growth stage 7: fruit development (mesostage 1)

Fruit is a syncarp (multiple fruit) composed of the individual fertilised ovaries (achenes). Each fertilised ovary develops into a fruitlet (bulb) with fleshy perianths (aril) enclosing a remnant of ovary and a seed. On the other hand, the unfertilized female flowers develop into tough, strap or string-like structures, called rags (perigones) which are placed between bulbs. Interestingly, ovary does not become fleshy in *Artocarpus* sp. and it develops into a dry pericarp whereas the lower part of perianth form edible fleshy pulp which may be firm or soft in texture and yellow or pink in colour. The outer surface of the syncarp is covered with a stiff rind and spines which are formed from the hardening of the middle and upper parts of the tubular perianth. The fleshy fruit axis is the modified inflorescence axis which is usually non-edible (Haq, 2006). The shape and size of syncarp, and shape, size, colour and number of bulbs vary with the germplasm. Fruit development of jackfruit follows sigmoidal growth pattern with three distinct phases; early slow growth (lag phase), rapid growth (log phase) and fruit maturation (diminishing growth phase). Lag phase continues for 2–3 weeks followed by rapid fruit development for 10–12 weeks. At maturation, fruit follows diminishing growth pattern which lasts for 5–6 weeks. Lag phase is characterised by slow development of syncarp, perianth and seed, whereas log phase is signified by rapid development of syncarp and bulb.

711. Initial fruit growth: syncarp at 10% of final size, perianth and seed inconspicuous, development of fruit axis continues (Fig. 1).

713. Fruit at 30% of final size: fruitlets start developing, fusion of perianth starts, spines still soft (Fig. 1).

715. Fruits at 50% of final size (Fig. 1): hardening of spines begin, development of fruitlets continue, seed soft, fruits are ready for harvest for culinary purpose (Fig. 1).

717. Fruits at 70% of final size: thickening of latex started, spine hardening continues, growth of perianth and perigone continues, bulb creamy white, seed hardening begins (Fig. 1).

719. Fruits at 90% or more of final size: advanced perianth growth, hardening of seed and perigones continues, seed coat creamy white in colour (Fig. 1).

Additional mesostages (2, 3, …, *n*) may be added as per the occurrence of fruiting flushes.

8. Principal growth stage 8: fruit maturation (mesostage 1)

Fruit maturation begins after completion of fruit development which may be judged by change in fruit colour, peduncle colour, perianth texture (soft and juicy), seed colour, fruit volume and cessation in latex secretion. Fruit maturation completes in 5–6 weeks. The harvesting of fruits begins in June and continues up to July. However, the time of harvesting may vary with genotypes.

811. Beginning of fruit maturation: fruit colour turns light green or light yellow, flattening of spines initiated, interspaces between spines increased, latex secretion reduced, aril light yellow in colour, seed coat turns light brown (Fig. 1).

815. Advanced maturation: peduncle colour starts turning light yellow or light brown, aril starts turning fleshy, aril turns light yellow, seed coat turns light brown, latex secretion ceased, fruits may be harvested (Fig. 1).

817. Fruit mature for commercial picking: fruit starts producing dull hollow sound when tapped, spine yields to moderate pressure, aril fleshy and yellow, seed coat turns light brown, seed maturation completed (Fig. 1).

819. Fruit over ripe: Spines yield to light pressure, flattening of spines completed, textural consistency of aril lost, aril exceedingly soft, sometimes seeds start germinating inside the bulb (vivipary) (Fig. 1).

Discussion

The extended BBCH scale gives a comprehensive overview of different phenological growth stages of jackfruit. Because it is an evergreen plant, vegetative shoots emerge throughout the year. However, vegetative growth is restricted during summer (April–May). The sequential progression of principal growth stages indicates that reproductive growth phases of jackfruit proceeds in parallel with the vegetative growth phases which signifies overlapping of phases (Fig. 2). However, temporal variation in the growth pattern of vegetative and reproductive shoots may vary according to the growing conditions (subtropical and tropical climatic

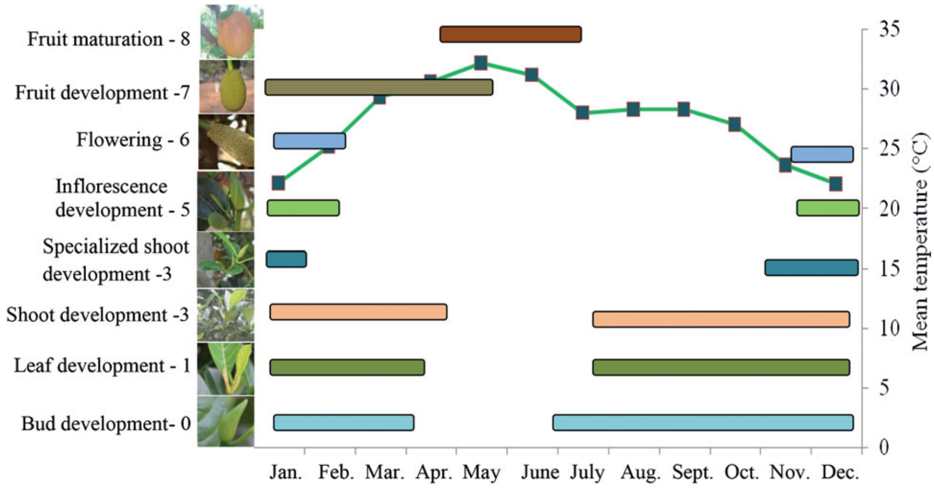

Figure 2 Sequential progression of principal growth stages of jackfruit. Bar indicates time elapsed in each stage; mean temperature during the study period (2015–2017).

conditions). Under eastern tropical climatic condition, reproductive phase in jackfruit starts from October and continues till February. However, the reproductive phase in a plant lasts for about 3 months including the development of footstalks. The period between December and January was most critical for the development of buds and spikes. There were 5–6 flushes of vegetative growth and 2 flushes of reproductive growth. The development of buds (011–019) is followed by leaf development (110–119) which is subsequently followed by the development of shoot (311–319). The events of bud and leaf development complete within 6–7 weeks, whereas shoot takes 10–12 weeks to attain its full growth. The developmental of footstalks (411–419) completes in 4–5 weeks which is followed by the development of reproductive buds and male and female spikes. The ratio between male and female spikes (sex ratio) varies with the genotype and climatic conditions. In low yielding germplasm the ratio was as high as 26.8, whereas in high yielding germplasm the ratio was 4.2. There was a high synchrony in the flowering phases of male and female spikes which facilitated high fruit set (>90%).

Knowledge about phenological stages is essential to accurately plan nutrient management, insect pest and disease management and harvesting of fruits at optimum stage. Nutrient management including micronutrients has been one of the key operations for obtaining better yield (Halder *et al.*, 2008). The application of nutrients at footstalk initiation (411–413) and fruit development (711–713) are crucial to ensure better yield and fruit quality. Jackfruit is affected by various insect pests but among them shoot and fruit borer is the most important (Soumya *et al.*, 2015). Phenological growth stages like 015, 313, 415, 513, 515 and 711 are highly prone to the damage of borer. Hence pest management at these stages is important for ensuring higher fruit set and yield. Stage of harvesting is central to determine fruit quality and marketability of jackfruit. It is consumed for vegetable, pickle and dessert. For vegetable and pickle, fruit should be harvested at 713 and 715 stages, whereas stages 815 and 817 are optimum for dessert purpose. Because jackfruit is climacteric, it should be harvested at optimum maturity as delay in harvesting significantly affects bulb quality and shelf life (Haq, 2006).

The phenological stages of jackfruit have been described for the first time according to the extended BBCH scale. The study will act as an effective tool not only for providing a consensual unified approach for standardisation of phenophases, but also for efficient orchard management including plant propagation for ensuring higher yield and fruit quality. The comprehensive description of various developmental stages of jackfruit will help in characterisation and selection of germplasm. Moreover, a precise knowledge on developmental phases of male and female spikes will facilitate crop improvement programme by identifying exact time of pollen presentation and duration of peak stigma receptivity. The study will also facilitate to assess the impact of weather conditions on crop phenology and to assess the adaptive strategy of germplasm under different agro-climatic conditions. Moreover, there is a need to integrate the phenological research with relevant disciplines like physiology, meteorology, agricultural entomology and plant pathology in order to understand the factors of phenological changes and their possible impact on overall performance of the plant.

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