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Phenological growth stages of dragon fruit (*Hylocereus undatus*) according to the extended BBCH-scale

Kundan Kishore

Central Horticultural Experiment Station (ICAR- Indian Institute of Horticultural Research), Aiginia, Bhubaneswar 751019, Odisha, India

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ABSTRACT

Hylocereus undatus is a night blooming, hemiepiphytic climbing cactus known for its high fruit value and market potential. However there is a dearth of information about its phenology. The present study defines codes and phenological stages of dragon fruit according to the extended BBCH (Biologische Bundesantalt, Bundessortenamt und Chemische Industrie) scale using three-digit numerical system which contributes to the standardization of its phenological stages. Seven principal growth stages, viz., bud development (0), shoot development (1), vegetatively propagated organ development (4), reproductive development (5), flowering (6), fruit development (7) and fruit maturation (8) have been described. A total of 40 secondary growth stages have been described and defined. The extended BBCH scale for dragon fruit is broadly applicable because it describes all the phenophases pertaining to vegetative and reproductive stages and their relative importance in crop management and improvement. The developed scale will act as a useful tool for adoption of effective crop management practices like nutrient management, pollination, plant propagation, timely harvest of fruits and pest management. The scale may also be effectively used for characterization of germplasm and assessment of climatic impact on crop phenology.

1. Introduction

Dragon fruit is a member of the order Caryophyllales and family Cactaceae which comprises of around 125–130 genera and 1400–1500 species. Most of the species are known for their ornamental qualities, however nearly 250 species are known for their fruit value (Hunt, 2006; Anderson, 2001; Bárcenas et al., 2011). Dragon fruit belongs to the genus *Hylocereus* (A. Berger) Britton & Rose which has 14 species and among them *H. undatus*, *H. monacanthus* (Lem.) Britton & Rose (previously known as *H. polyrhizus*), *H. costaricencis* and *H. megalanthus* (previously known as *Selenicereus megalanthus*) are the most cultivated species around the world (Nerd and Mizrahi, 1997; Tel-Zur et al., 2011). Cytological observations show that *H. undatus*, *H. monacanthus* and *H. costaricencis* are diploid (2n = 2x = 22), whereas *H. megalanthus* is an allotetraploid (2n = 4x = 44) derived from natural hybridization between two closely related diploid taxa (Lichtenzveig et al., 2000; Tel-Zur et al., 2004). As per the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, *H. undatus*, the most widely cultivated species, is listed as Data Deficient because the native range is not known with any certainty and hence not much is known about its extent of occurrence and population size. Whereas *H. monacanthus, H. costaricensis* and *H. megalanthus* are listed as Least Concern because they are widely distributed in the Central and South America (Duran et al., 2013; Hammel, 2013; Loaiza and Ostalaza, 2013; Ostalaza and Loaiza, 2013). Like other cacti, dragon fruit is highly adaptable to a new environment due to their ability to tolerate abiotic stress like drought and temperature extremes. Modification of the stem for water storage (succulent), absence of leaves, presence of waxy layer on stem, night-time opening of the stomata and presence of CAM (Crassulacean acid metabolism) photosynthetic pathway enable the plants to adapt under adverse climatic conditions (Nie et al., 2015). The species of *Hylocereus* are primarily distinguished on the basis of their fruit morphology, pulp colour, areole characters and number and form of the spines (Ortiz-Harnandez and Carrillo-Salazar, 2012). The fruits of *H. undatus* are characterized by red peel and white pulp, whereas red fruit with red pulp is the characteristic feature of *H. monacanthus* and *H. costaricencis*. The fruits of *H. megalanthus* are characterized by knobby yellow peel with white flesh. Dragon fruit is known for its rich nutrient contents specially vitamin C, phosphorus, calcium as well as its fiber content, antioxidative and medicinal properties. It also contains betacyanins (water soluble pigments) which impart red colour to pulp and peel (Wybraniec et al., 2007).

E-mail addresses: kkhort12@gmail.com, kkhort2003@yahoo.com

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Dragon fruit is known by different names like Pitaya, Pitahaya, Strawberry pear, Queen of the Night, Night blooming Cereus, Belle of the Night, Thang, etc. It has been widely distributed in tropical and subtropical regions of the world and it has traditionally been consumed in Latin American countries (Briton and Rose, 1963). However; its niche in the exotic fruit market has recently grown in Israel, Australia, Vietnam, Malaysia, Indonesia, Thailand, Philippines, Taiwan and Sri Lanka (Nobel and De la Barrera, 2002). Dragon fruit is a perennial, hemi-epiphytic and climbing cactus, characterized by fruits with large scales and presence of aerial roots. It has triangular, succulent stem with wavy ribs possessing areoles and spines. The areole is one of the unique features that cacti developed possibly in adaptation to the climatic condition. It is a highly specialized structure with very condensed nodes surrounded by multicellular hairs (trichomes) that give the areole a hairy or woolly appearance. Areoles are borne on ribs and act as points of origin for spines and flower buds. Areoles and spines vary greatly in shape, colour and appearance and they are considered important morphological descriptors for characterization of species. Dragon fruit produces large (25–28 cm), attractive, bisexual, bell shaped and night blooming flowers from areoles of mature shoot. Initiation of reproductive phase is marked by the emergence of spherical cream colour floral buds from areoles. The development of a floral bud to a fully opened flower takes 25–35 days. Dragon fruit is a photoperiod-responsive crop as its flowering is induced by long days. In tropical climate the plants can have up to 4–6 flowering flush per year (Pushpakumara et al., 2005; Jiang et al., 2012). Flower is borne with an inferior ovary which is surrounded by receptacle, forming a structure called a pericarpel which is surrounded by green photosynthetic foliaceous scales (bracts) which are attached with fruits till maturation. The apical portion of pericarpel grows continuously forming a pronounced hypanthium (floral tube). The outer surface of floral tube possesses scale-like bracts which develop into parianth (sepaloids and petaloids) during flower development. Flowers have many stamens (arranged in layers) and a solitary pistil which is characterized by an inferior ovary, located at the base of a hypanthium, a long style and a highly branched stigma. Flower secretes moderate amount of nectar from nectarial tissue located on the inner surface of the hypanthium (Almeida et al., 2013). Flowers start opening in the evening and anthesis is completed within 3–4 h. Pollination is carried out by nectar feeding nocturnal pollinators like bat and hawk moth. Pollination is followed by the wilting of flower which begins in the morning. Among important species of *Hylocereus*, *H. undatus* and *H. megalanthus* are self-fruitful, whereas *H. monacanthus* and *H. costaricensis* are self-unfruitful as cross-pollination with other species led to high fruit set (Valiente-Banueta et al., 2007). Fruit of *Hylocereus* spp., an epigenous berry, develops from both ovary and pericarpel which attains maturity between 30 and 35 days after fruit set (Nerd et al., 1999). Fruits are medium to large, oblong with delicate and mildly sweet flesh containing numerous soft black seeds. Dragon fruit is consumed fresh or used for jellies, marmalades, jams, wine and beverages (Chuah et al., 2008).

The systematic documentation of phenological stages is essential to achieve higher productivity and better fruit quality since important cultivation practices are based on phenophases of plants. Phenological stages of plants are described using the BBCH (Biologische Bundesantalt, Bundessortenamt, und Chemische Industrie) scale with its uniform coding and description system (Lancashire et al., 1991; Hack et al., 1992; Meier, 1997). The basic BBCH scale is represented by two digits representing primary and secondary growth stages. This scale consists of 10 principal stages (0–9), which are further divided into 10 secondary (0–9) growth stages. Each stage represents clearly recognizable and distinguishable developmental phases of plant. The extended BBCH scale provides more detailed description about crop by considering mesostages (1-n), which are incorporated between the primary and secondary stages, resulting in a three-digit scale (Lancashire et al., 1991; Hack et al., 1992). The BBCH-scale has so far been widely used to describe phenological stages of cereals, oilseeds, bean (Lancashire et al., 1991; Weber and Bleiholder, 1990), beet (Meier et al., 1993), potato (Hack et al., 1993) and vegetables (Feller et al., 1995). Fruit crops, such as grapevine (Lorenz et al., 1995), stone fruits, pome fruits, strawberry (Meier et al., 1994), citrus (Agusti et al., 1997), loquat (Martinez-Calvo et al., 1999), banana (Gonzales et al., 2002), guava (Salazar et al., 2006), kiwifruit (Salinero et al., 2009), mango (Rajan et al., 2011; Hernandez-Delgado et al., 2011), avocado (Alcaraz et al., 2013), lychee (Wei et al., 2013), longan (Pham et al., 2015), *Annona squamosa* (Liu et al., 2015), sweet cherry (Fadon et al., 2015), jujube (Hernandez et al., 2015), *Pyrus pyrifolia* (Martínez-Nicolás et al., 2016) and pineapple (Zhang et al., 2016) have already been described in detail according to the BBCH-scale.

Limited studies conducted on phenology of dragon fruit primarily dealt with the interaction of climatic factors with the reproductive growth of plant (Jiang et al., 2011; Osuna-Enciso et al., 2016). A few examples are there wherein the BBCH-scale has been used to describe only some of the developmental stages of *Opuntia* (Kharrassi et al., 2015). Notwithstanding the significant economic and ecological significance of dragon fruit, its phenological stages are not well understood and no specific phenological scale has yet been developed so far. Therefore the present study defines phenological growth stages of dragon fruit using extended BBCH scale. This work will contribute to the standardization of phenological studies, quantitative analysis of growth cycle and efficient implementation of crop management practice in across the dragon fruit growing nations.

2. Materials and methods

Phenological stages of *Hylocereus undatus* was studied according to the BBCH scale. The experiment was conducted at the Central Horticultural Experiment Station (ICAR-IIHR), Bhubaneswar (elevation: 45 m amsl; latitude: 20°27′ N; longitude: 85°40′ E), which is located in the eastern coastal region of India. The region experiences tropical hot and humid climate with the 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 characterized by relatively long spell of rainfall (June–Sept), summer (February–May) and brief spell of mild winter (December–January). Data on vegetative and reproductive stages at different developmental phases were collected from two year old vine of *H. undatus* during 2015–16. Data on shoot growth were recorded weekly, whereas data on the development of vegetative and reproductive buds, flowering, fruit development and fruit maturation were recorded at an interval of two days. Ten plants of each species were selected for experimentation.

The extended BBCH scale with three digit code was used to define and describe phenological stages of dragon fruit. The first digit describes the principal growth stage, second digit specifies the mesostages and the third digit signifies secondary growth stages (Hack et al., 1992; Meier, 2001). The growth cycle of dragon fruit has been represented by 7 clearly recognizable principal growth stages, including vegetative bud development (stage 0), shoot development (stage 3), development of vegetative propagated organ (stage 4), reproductive development (stage 5), flowering (stage 6), fruit development (stage 7) and fruit maturation (stage 8). Whereas, the stages 1 (leaf development), 2 (formation of side shoots/tillering) and 9 (senescence, beginning of dormancy) were not considered because they are not applicable in dragon fruit. The seven principle growth stages were further divided into 10 secondary stages

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