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Codification and description of phenological growth stages of sapota (*Manilkara zapota*) according to the extended BBCH scale

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ABSTRACT

Sapota (*Manilkara zapota*) is an important evergreen fruit crop cultivated in the tropics with a high market potential. However its phenology has been poorly described. The present study defines codes and phenological stages of sapota according to the extended BBCH (Biologische Bundesantalt, Bundessortenamt und Chemische Industrie) scale using three-digit numerical system. A total of 7 principal growth stages, viz., bud, leaf and shoot development, reproductive development, flowering, fruit development and fruit maturation have been described. In addition, 41 secondary growth stages have also been described. The description of the phenological stages is combined with illustrations for clarification. Moreover, the sequential progression of principal growth stages has been presented to describe growth pattern and climatic requirements for different phases. The extended BBCH scale for sapota is broadly applicable because it describes all the phenophases pertaining to vegetative and reproductive stages and their relative importance in crop management and crop improvement. The study will act as a tool for adoption of better crop management practices (nutrient management, flower and fruit drop management, irrigation scheduling, monitoring and management of pests and timely harvest of fruits), crop improvement, characterization of germplasm and impact assessment of climate change on phenology.

1. Introduction

Sapota (*Manilkara zapota* (L.) P. Royen), an evergreen tropical tree, is native of tropical America and probably originated in the southern Mexico. It is now widely cultivated in India, Sri Lanka, Malaysia, West Indies, Mexico and other tropical countries (Papenoe, 1974). India is the leading sapota producing country in the world with an annual production of 1.74 million MT. Central and southern parts of India are major sapota growing belts due to climatic suitability and availability of promising varieties (Anonymous, 2014). A number of cultivars of sapota viz., Badam, Badami, Bombay, Calcutta Round, CO-1, CO-2, Cricket Ball, DHS-1, DHS-2, Dwarapudi, Guruvayya, Gavaraiah, Pilipatti, Gutti, Jhumakiya, Kalipatti, Kirtibarti (big), Kirtibarti (long), Krishna Rao, Mohangooti, Morabba, PKM-1, PKM-2, Oval, Pala, Pakala Oval, Seedless and Vavilvalasa, are commercially grown for fruits and processed products in different agro-climatic conditions of India (Dinesh and Reddy, 2000; Vahora et al., 2009).

Sapota belongs to the family Sapotaceae which consists of 58 genera and about 1250 species in subtropical and tropical regions of the world (Govaerts et al., 2001; Swenson et al., 2007). Other fruit trees of economic importance in the Sapotaceae family are star apple (*Chrysophyllum cainito*), egg fruit (*Puteria campechiana*), abiu (*Puteria caimito*), mahua (*Madhuca longifolia*), miracle fruit (*Synsepalum dulcificum*) and khirni (*Manilkara hexandra*). Sapota grows well in a wide range of climatic conditions from wet tropics to dry cool subtropical areas. But it prefers humid tropical climate. Sapota is known by various names like Sapodilla, Chickle gum, Chiku, Chikoo and Naseberry in different parts of the world. It is a rich source of sugar, protein, and minerals such as calcium, phosphorous, iron and potassium. It also has high anti-oxidative capacity (Ribeiro da Silva et al., 2014).

Sapota has dense crown and a characteristic sympodial branching pattern, wherein the young branches are arranged horizontally. Leaves are medium, alternate, elliptic to ovate, glossy, spirally arranged and clustered at shoot tip. Flowers are solitary, small, campanulate, bisexual, greenish white with six sepals arranged in two whorls and a gamopetalous six-lobed corolla. The androecium is adnate to the corolla which consists of an inner whorl of fertile stamens. Sapota has solitary pistil with a stigma, style and a superior ovary with 4 or 5 locules each with a single axile ovule. Fruits are ovoid to round in shape, dull brown in colour with a firm skin. Unripe fruit contains ample latex that reduces with the maturity of fruit. The fruit, typically a berry, has yellow to brown sweet pulp

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with malty flavour and grainy texture akin to that of a ripe pear. Each fruit contains 1–6 or even more hard, glossy, and black seeds (Ray, 2002).

Phenology deals with seasonal timing of recurrent biological events which are intimately linked to the developmental phases of plant species. The timing of the switch between vegetative and reproductive phases that occurs in concert with flowering is crucial for reproductive success of plants (Caradona et al., 2014). Phenology has received much attention in recent past as the developmental stages of plants are influenced in response to climate. The BBCH (Biologische Bundesantalt, Bundessortenamt und Chemische Industrie) numerical scale, a system for uniform coding of growth stages, has been widely used for describing phenological stages of plants. The basic BBCH scale, represented by two digits, consists of primary and secondary scales, each of which is subdivided into 10 (0–9) clearly recognizable 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). Whereas, 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). Both scales (simple and extended) have been widely used to describe phenological stages of many fruit crops such as mango (Rajan et al., 2011; Hernandez-Delgado et al., 2011), banana (Gonzales et al., 2002), citrus (Agusti et al., 1997), guava (Salazar et al., 2006), kiwifruit (Salinero et al., 2009), 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* (Martinez-Nicolas et al., 2016) and pineapple (Zhang et al., 2016). The development of characterization tools for precise and standardized description of phenological stages of sapota is essential for research experiments, breeding programmes, characterization and conservation of germplasm and crop management (Gotor et al., 2008). The developmental stages of sapota have not yet been defined and described. Moreover, the characterisation of phenological stages such as bud development, flowering, fruit development and fruit ripening is essential to achieve more yield and better fruit quality, since a number of agronomical practices (fruit drop management, irrigation, nutrient management, pest management, etc.) rely on the recognition of specific phenological stages. This study applies the extended BBCH scale to define phenological growth stages of sapota and provide information for researchers and growers for better implementation of crop improvement program and efficient crop management practices, respectively.

2. 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 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 phases at different developmental stages were collected from 15 years old grafted trees of six sapota varieties namely Cricket Ball, Kalipatti, DHS-1, DHS-2, PKM-1 and CO-1 during two annual growing seasons (2014–2015; 2015–2016). Data on various phenological stages were recorded weekly (bud, inflorescence and flower), or twice per month (shoot, fruit and dormancy) depending on the developmental stages from 60 tagged branches located in 12 randomly selected trees (2 plants from each variety).

In three digit code of extended BBCH scale, 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 proposed extended BBCH phenological scale for sapota is represented by 7 principal growth stages out of 10 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). Whereas, the stages 2 (formation of side shoots/tillering), 4 (development of harvestable vegetative plant parts or vegetatively propagated organs/booting) and 9 (senescence, beginning of dormancy) were not considered because they are not applicable in sapota. Principle growth phases are further divided into 10 secondary stages (0 to 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 phenological phase. Mesostages (1, 2, 3,. . ., n – 1, n) were used to describe different vegetative and floral flushes during the growth period. For example, value 5 of principal stage 3 (shoot development) is assigned when shoot attains 50% of final shoot length in first flush and its identification would be 315. Likewise, stage 713 identifies the value 3 of the principal stage 7 (fruit development), which represents fruit at about 30% of final size. Similarly, value 9 of principal stage 5 (reproductive development) of first flush (mesostage 1) indicates end of flower extension and is identified as 519. The phenological growth stages and flower development were sequentially characterized and photographed with a digital camera (Nikon D3200). In order to characterize development of reproductive parts, five flower buds of each variety were collected at different stages during February–March and July–August and dissected under a stereoscopic microscope (Leica S8 APO, Germany), and photographed.

3. Results

The phenological growth stages of sapota covered the entire year cycle, starting with bud development and vegetative growth and ending with fruit maturation (Table 1). The description is divided in seven principal growth stages; three for vegetative growth (bud, leaf and shoot development) and four for reproductive growth (inflorescence emergence, flowering, fruit development and fruit maturation) of the ten principal growth stages of the BBCH scale. Within principal growth stages a total of 41 secondary growth stages are described (Figs. 1–3). Under each principal growth stage, two mesostages are also taken into account.

3.1. Principal growth stage 0: vegetative bud development

3.1.1. First vegetative flush (mesostage 1)

010. Vegetative buds dormant: foliar buds are completely closed (Fig. 1).

011. Beginning of bud swelling: buds start separating (Fig. 1).

013. End of bud swelling: buds start elongating (Fig. 1).

015. Leaf buds start separating (Fig. 1)

017. Beginning of bud break: leaves visible, lamina is still closed (Fig. 1)

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