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Phenological growth stages of cardamom (*Elettaria cardamomum* Maton): Detailed identification and description using the extended BBCH scale

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Abstract

Cardamom (*Elettaria cardamomum* Maton) is an important spice crop with high market value. In this study, we describe the phenological growth stages of cardamom using a three-digit extended Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie (BBCH) scale, which includes eight principal growth stages, comprising four vegetative, two reproductive and two capsule development stages. Additionally, we identified 45 secondary stages within these principal growth stages, providing a comprehensive characterisation of the crop's growth progression, including bud development, leaf emergence, tillering and shoot development, while the reproductive stages included inflorescence emergence and flowering. The capsule development stage details the maturation process of capsules. The study also highlights the parallel occurrence of tillering, shoot development and inflorescence emergence stages during specific growth phases. The knowledge of growth stages facilitates timely interventions, optimising crop management strategies and enhancing overall crop productivity. Additionally, these findings offer valuable insights for breeding programmes and the selection of superior genotypes, contributing to the sustainable cultivation and economic viability of cardamom as an important export-oriented spice crop.

Highlights

- BBCH scale provides uniform coding for different growth stages of cardamom.
- Identified and described eight principal growth stages (PGS).
- PGS comprises of 4 vegetative, 2 reproductive and 2 capsule development stages.
- 45 secondary stages were identified within 8 principal growth stages.
- Tillering, shoot development and inflorescence emergence occurs parallelly.

KEYWORDS
BBCH, cardamom, critical stages, crop management, phenology

1 | INTRODUCTION

Cardamom is a perennial herbaceous rhizomatous plant belonging to the Zingiberaceae family. It belongs to the genus *Elettaria* and species *cardamomum*, which is a monotypic genus in India. It originates from the moist evergreen forests of the Western Ghats of Southern India (Ravindran, 2002) and is cultivated at an elevation of 700–1500 m above mean sea level (MSL). It is often referred to as the 'Queen of Spices' due to its pleasant aroma and taste. It is a highly priced spice in the world, after saffron and vanilla. The major cardamom producing countries in the world include Guatemala, India, Sri Lanka, Papua New Guinea and Tanzania. In India, cardamom is cultivated in an area of 69,190 ha, production 23,340 tons during 2021–2022 in Kerala, Karnataka and Tamil Nadu (www.indianspices.com). Other important genera belonging to Zingiberaceae include *Alpinia*, *Amomum*, *Curcuma*, *Hedychium*, *Kaempferia* and *Zingiber*. Among these genera, important spice crops include large cardamom, ginger and turmeric.

Leafy shoots of cardamom arise from its underground rhizomatous stem, growing up to 2–3 m in height, petioles are up to 2.5 cm long, lamina up to 1 m $\times$ 15 cm, lanceolate, acuminate, lightly pubescent or glabrous below. The inflorescence is known as a panicle and possesses a long cane-like peduncle with nodes and internodes (Burtt & Smith, 1983). Flowers are borne on a modified helicoid cyme called the cincinnus and each of the cincinni consists of many flowers. In almost all cardamom genotypes, the flower labellum is white with violet streak, except in the white flower variety where the complete flower is white. Based on the nature of the inflorescence, cardamom types are classified into Malabar (prostrate panicles), Mysore (erect panicles) and *Vazhukka* (semi-erect panicles) (Sastri, 1952). Generally, 2–4 panicles emerge from the tiller base. Cardamom is a cross-pollinated crop, and flowers are pollinated by honeybees. Capsules are thin-walled with globose or ellipsoid shape, which vary with variety/genotype. The capsules are green in colour and turn golden yellow during ripening. Each capsule contains many seeds, varies from 10 to 20 and the seeds are white when unripe and on maturity become black, which is covered by a thin mucilaginous membrane (Madhusoodanan et al., 2002).

In addition to culinary uses, the presence of several compounds in essential oils makes cardamom a perfect candidate for medicinal uses. Compounds such as 1,8-cineole, α-terpinyl acetate, α-terpineol, sabinene and nerol (Ashokkumar, Murugan, Dhanya, Raj, & Kamaraj, 2020), linalyl acetate, linalool and geraniol (Chegini & Abbasipour, 2017; Singh et al., 2008) and several flavonoids and carotenoids have huge potential in medicine (Ashokkumar, Murugan, Dhanya & Warkentin, 2020). In addition, several fatty acids, such as myristic acid, palmitic acid, palmitoleic acid, stearic acid, oleic acid, linoleic acid, α-linolenic acid, arachidic acid and eicosenoic acid (Parry et al., 2006) also impart health benefits.

Phenological growth stages indicate the impact of climate on the biosphere. The BBCH scale provides uniform coding for similar phenological growth stages in mono- and dicot plants (Meier et al., 2009). On this scale, 10 principal growth stages, from germination to senescence, are described. The principal growth stages describe the time span between the developmental stages of a plant, and the secondary stages are short developmental stages between the two principal growth stages. The first two digits indicate the principal and secondary stages (Bleiholder et al., 1989), whereas the third digit represents the mesostages that occur between the principal and secondary stages (Hack et al., 1992; Lancashire et al., 1991).

The BBCH scale is extensively used for both annual and perennial crops. The modified BBCH scale has been proposed for many horticultural crops namely, coffee (Pulgarín et al., 2002), cocoa (Niemenak et al., 2010), mango (Delgado et al., 2011), sapota (Kishore & Mahanti, 2016), pineapple (Zhang et al., 2016), jackfruit (Kishore, 2018), cashew (Adiga et al., 2019), mangosteen (Awachare & Upreti, 2020), stevia (Bihan et al., 2020) and jamun (Singh et al., 2021). With a special reference to spices, phenology has only been studied in saffron (Corcoles et al., 2015) and in zingibers, and only flowering phenology has been studied in greater galangal (Divya et al., 2023) and torch ginger (Choon, 2016).

Cardamom is an important spice crop; its growth and yield are affected by biotic and abiotic factors. Climatic factors and the occurrence of pests and diseases are critical during particular crop growth stages. The objective of this study was to identify and describe the phenological growth stages of cardamom using the extended BBCH scale and assess their significance in crop management and cultivation practices.

2 | MATERIALS AND METHODS

2.1 | Study location

Phenological studies were conducted at the ICAR-Indian Institute of Spices Research, Regional Station, Appangala, Madikeri, Karnataka. The geographical coordinates of the location are 12°26′ N latitude, 75°45′ E longitude and the elevation is 920 m above the mean sea level. The region experienced a mean annual rainfall of 3113 mm, with a mean maximum temperature of 26.9°C and a mean minimum temperature of 12.5°C during the study period.

2.2 | Plant material and experimental design

Two varieties of cardamom, Appangala 1 and Appangala 2, were selected for phenological studies and 50 plants were tagged to monitor their phenological growth stages. Observations were recorded at regular intervals based on the growth rates of the stages. Observations were recorded once every 2 days for leaf development, capsule development and flowering, and once a week for bud development, side shoot/tillering, shoot development, inflorescence emergence and the capsule ripening stage.

2.3 | Phenological scale

The extended BBCH scale (Hack et al., 1992) was used to define various phenological growth stages in the cardamom. Of the 10 stages in the BBCH scale, only the clearly recognisable and distinguishable principal growth stages were used in this study. A total of eight principal growth stages were employed, out of which four were related to vegetative growth bud development (0), leaf development (1), side shoot/tillering (2), shoot development (3) and other 4 are for inflorescence emergence (5), flowering (6), capsule development (7) and capsule ripening (8).

2.4 | Phenological stage codes

Each principal growth stage is represented by a first digit ranging from 0 to 8. Secondary stages are denoted by the second digit, and the third digit represents numerical values between 0 and 9, which depict the growth of buds, shoots, leaves, inflorescences, flowers and capsules.

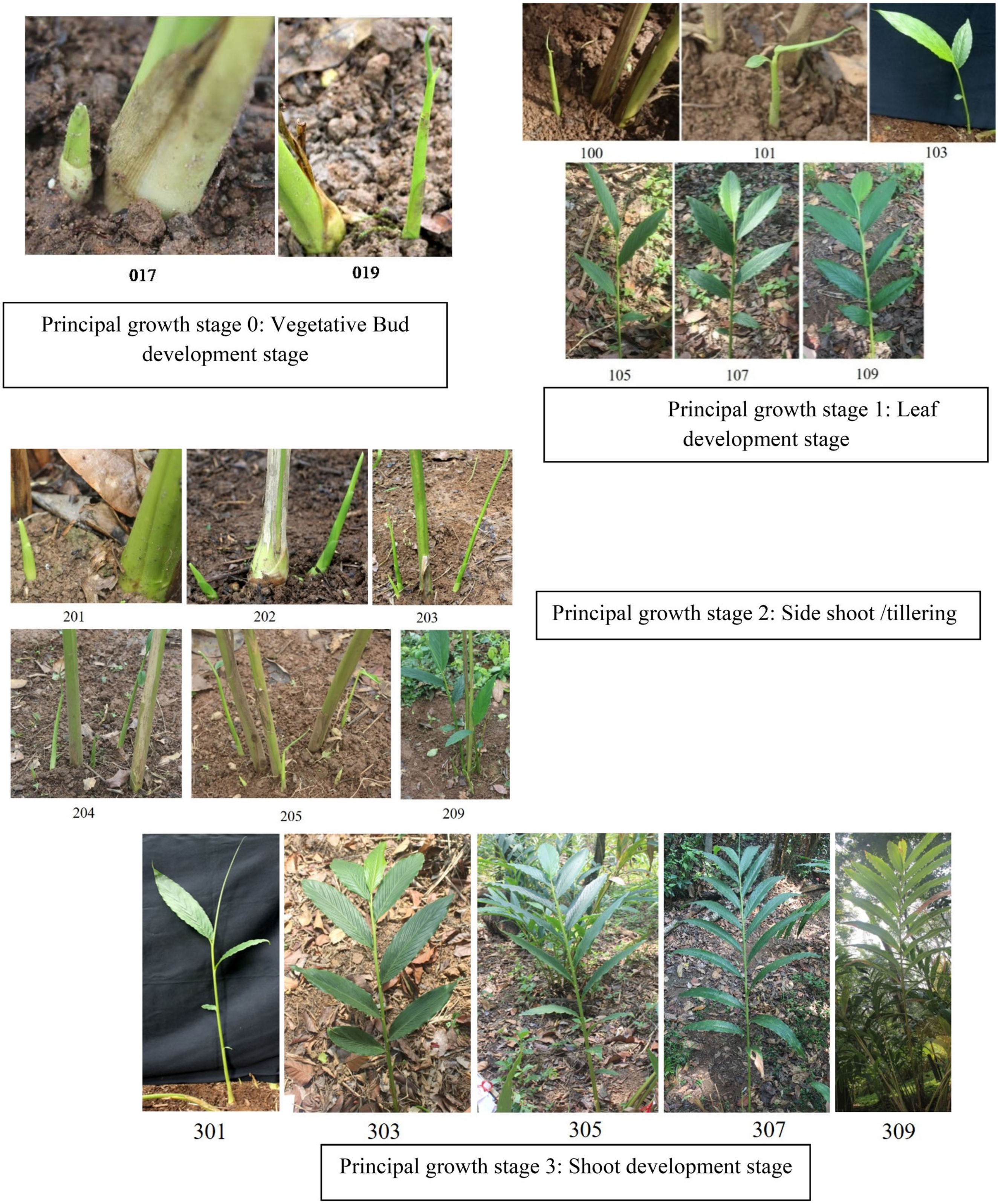

FIGURE 1 Vegetative development stages of cardamom according to the extended BBCH scale.

FIGURE 2 Reproductive, flowering and capsule development stages of cardamom as per the extended BBCH scale.

2.5 | Data collection

Observations were recorded for two varieties, Appangala 1 and Appangala 2, during two consecutive years, 2021–2022 and 2022–2023. Phenological data were collected and recorded for each principal growth stage and their respective secondary stages throughout the plant growth period.

3 | RESULTS

Out of 10 stages, eight phenological growth stages were identified in the cardamom. The eight growth stages were subdivided into four vegetative stages, two reproductive stages, and two capsule development stages. A total of 45 secondary stages were identified among the phenological growth stages (Figures 1 and 2).

3.1 | Principal growth stage 0: Vegetative bud development stage

As cardamom is a rhizomatous plant, initiation of vegetative buds starts adjacent to the mother plant inside the soil, which occurs inside the soil and is not visible. Hence, the beginning of bud break takes place 30–45 days after planting the sucker in the field (usually cardamom is planted during the rainy season, June–August).

017. Beginning of bud break—The bud becomes completely visible above the soil surface, around 1–1.5 cm in size and appears light green.

019. End of bud break—The bud starts elongating and scales become clearly visible.

3.2 | Principal growth stage 1: Leaf development stage

Leaf development begins at the end of bud break. New leaves begin to unfold from the elongating buds, and this stage progresses in parallel with the shoot development.

100. First leaf begins to expand—First leaf begins to expand from the elongating bud.

101. First leaf unfolded from the first tiller—First leaf is completely opened, very small and light green in colour.

102. Second leaf of first tiller unfolded—Second leaf is completely unfolded, larger than the first leaf and light green in colour.

103. Third leaf of first tiller unfolded—Third leaf is completely unfolded, light green in colour.

104. Fourth leaf of first tiller unfolded—Fourth leaf is completely unfolded and light green.

105. Fifth leaf of first tiller unfolded—Fifth leaf is completely unfolded and light green in colour.

106. Sixth leaf of first tiller unfolded—Sixth leaf is completely unfolded and initially developed leaves turn dark green and the mid rib is clearly visible.

107. Seventh leaf of first tiller unfolded—Seventh leaf is completely unfolded.

108. Eighth leaf of first tiller unfolded—Eighth leaf is completely unfolded.

109. Nine or more number of leaves from first tiller unfolded—More leaves are unfolded and the initially opened leaves become dark green in colour.

When there are 15–16 leaves in a tiller, the first 1–2 leaves dry. The side-shoot/tillering stage occurred in parallel with this stage. The initially formed leaves are small in size.

3.3 | Principal growth stage 2: Side shoot/tillering

Tillering starts in cardamom 30–45 days after planting the suckers in the field. This stage starts with vegetative bud development, and leaf development occurs in parallel with tiller development. Tiller production in cardamom is a continuous process, and the peak will occur during the rainy season (June–September). The number of tillers depends on good nutrition and availability of water. During the summer season, tiller production ceases.

201. First tiller visible—First tiller is visible above the soil surface and is light green in colour.

202. Second tiller visible—Second tiller becomes visible above the soil surface, light green in colour and leaves start emerging from first tiller.

203. Third tiller visible—Third tiller is visible above the soil surface.

204. Fourth tiller visible—Fourth tiller emerges above the soil surface and the first developed tiller will have around two leaves.

205. Fifth tiller visible—Fifth tiller emerges above the soil surface and the earlier developed 2–3 tillers will have leaves.

206. Sixth tiller visible—Sixth tiller emerges above the soil surface.

207. Seventh tiller visible—Seventh tiller emerges above the soil surface.

208. Eighth tiller visible—Eighth tiller is above the soil surface.

209. Nine or more tillers visible—At this stage, nine or more tillers become visible, and the initially developed 2–3 tillers will have 3–4 leaves.

3.4 | Principal growth Stage 3: Shoot development stage

Shoots start elongating after emergence, and development continues along with leaf development. The internodal length between the scales increases with the growth of the shoot, and from each scale, one leaf develops. In the beginning, shoots are tender and light green in colour, with mature shoots becoming sturdy. Each developing shoot requires 10–12 months for panicle production, and it will take 18–20 months from 301 to 309 stage.

301. Beginning of shoot growth—Shoot at 10% of its maturity, 3–4 leaves are completely unfolded, and stem is tender light green in colour.

303. Shoots at 30% maturity—Shoots are 30% mature with 8–9 leaves and shoots become slightly sturdy. The bottom first leaf starts senescence (yellowing) and the internodal length increases.

305. Shoots at 50% maturity—Shoots are 50% mature with 13–14 leaves. The shoot is sturdy, and the bottom first leaf dries up completely, while the second leaf starts yellowing. Panicle initiation and flowering were also initiated.

307. Shoots at 70% maturity—Shoots are 70% mature with 18–19 leaves. Shoots remain sturdy, three leaves completely dry up and 4^{th} leaf starts yellowing. Flowering and capsule development were continued.

309. Shoots at 90% maturity—Shoots are 90% mature, with 23–24 leaves. Shoots are very sturdy, with 8–9 leaves dry up, and panicle development is almost complete.

3.5 | Principal growth stage 5: Inflorescence emergence stage

Inflorescence emerges from the base of the tiller, and from the beginning of reproductive bud swelling to the end of panicle development takes approximately 6–7 months. Inflorescence emergence began during February–March after the receipt of pre-monsoon showers, and peak panicle initiation was observed after the onset of the monsoon (June–August). This stage continues in parallel with the principal growth stages 6, 7 and 8, that is, flowering, capsule development and maturity/ripening.

501. Beginning of reproductive bud swelling—Swelling of buds is seen in the lower portion of the sucker/tiller, covered by scales. Reproductive buds are smaller than vegetative buds and grow horizontally on the soil surface.

503. Bud starts elongating—Bud breaks open the scales, becomes visible and light green.

504. Elongation of panicle—Panicle starts elongating, bracts open and separation of cincinni is observed.

505. More laterals separated—Panicle elongation continues and more laterals are separated. Flowering and capsule setting is observed.

509. End of panicle development—Panicle elongation ceases but flowering, capsule setting and development continues.

3.6 | Principal growth stage 6: Flowering

Flowering in the cardamom is non-synchronous and occurs parallel to inflorescence development. Flowering occurs during the elongation of the panicle stage (504), and flowering continues for 4–5 months. It takes approximately 60–80 days to open the first flower in a panicle. Peak flowering was observed in June–August. This stage parallels the inflorescence emergence stage (504–509), capsule development stage (710–719) and capsule ripening stage (810–819).

610. First flower opened—First flower in the panicle is opened. This stage goes in parallel with inflorescence emergence stage.

611. Beginning of flowering—Up to 10% of the flowers in a panicle are opened. This stage parallels inflorescence emergence and capsule development stages.

613. Early flowering—About 30% of the flowers are opened.

615. 50% of flowering—About 50% of the flowers are opened in a panicle and capsule harvesting begins.

617. 70% of flowering—70% of the flowers are opened in a panicle and approximately 25–30% of capsules in a panicle are harvested.

619. End of flowering—The last flower in the panicle opens, and flowering is completed. Almost 40–50% of the capsules in the panicle are harvested.

The flowers start opening from 4.30 am and fully open by 5.30 am. Anther dehiscence occurs between 6.30 and 7.30 am (Kuriakose et al., 2009). The flowers wither within a day.

3.7 | Principal growth stage 7: Capsule development stage

Cardamom is a cross-pollinated plant pollinated by honey bees. After effective pollination, fruit set was observed within 4–5 days. As the panicle growth habit is non-synchronous panicle development, flowering, capsule development, and capsule ripening occur side by side. The time taken from capsule set to final harvesting was approximately 110–120 days.

710. Capsule set—Capsule set is observed after effective pollination. Capsule appears yellowish in colour.

711. Capsule at 10% development stage—Capsule is 10% of its final size. The capsule turned light yellowish in colour. The seed locules started to form and were white in colour.

713. Capsule at 30% development stage—Capsule attains 30% of its final size, and its colour starts turning light green. Seed locules remained white.

715. Capsule at 50% development stage—Capsule reaches 50% of its final size, seed locules clearly visible, and white in colour. The capsules were green in colour.

717. Capsule at 70% development stage—Capsule attains 70% of its final size. The capsule turns dark green, and the seeds are white in colour.

719. Capsule at 90% development stage—Capsule reaches 90% of its final size, capsule is dark green in colour, and the seeds start turning black.

3.8 | Principal growth stage 8: Capsule ripening/maturity

Capsules reach physiological maturity when they are green, with fully developed shoulders and black seeds. This is the most appropriate stage for capsule harvesting. If the capsules remain on the plant past this stage, they become fully ripened and turn yellow. The capsules may split open during the drying process.

810. Physiological capsule maturity—Capsule is ready for harvesting, appearing green in colour and contains black seeds inside.

819. Capsule fully ripened—Capsule completely ripened and turns pale yellow in colour. Seeds are black in colour.

4 | DISCUSSION

The extended BBCH scale provides an overview of plant developmental stages, encompassing the vegetative, reproductive and fruit maturation stages (Kishore & Mahanti, 2016). Its application goes beyond mere categorisation as it aids in the characterisation of germplasm, scheduling cultural practices, crop improvement and studying the effects of climate change (Chmielewski, 2003; Kishore et al., 2017). Kuruvilla et al. (1992), Pattanshetti & Prasad (1972) and Parameshwar (1973) studied tiller production, panicle development and flowering in cardamom plants. In the present study, distinct phenological stages in cardamom were identified and described by utilising 3-digit BBCH scale.

Eight principal growth stages were identified in cardamom, which included four vegetative stages, two reproductive stages and two fruit maturation stages. A total of 45 secondary stages were identified, and codes were assigned as follows: 37 in cashew (Adiga et al., 2019), 59 in mango (Delgado et al., 2011), 41 in sapota (Kishore & Mahanti, 2016), 35 in avocado (Alcaraz et al., 2013), 36 in jamun (Singh et al., 2021), in a few horticultural crops.

Cardamom is a crop that is significantly affected by moisture stress, and deficits in summer showers may lead to a reduction in yield (Ankegowda, 2011; Hegde & Korikanthimath, 1996). Cardamom requires irrigation during the summer months, until the onset of the monsoon. Providing irrigation during the summer will have a positive impact on tiller production, panicle development, and fruit set. Key stages, namely, vegetative bud development (017–019), side shoot/tillering (principal growth stage 2), inflorescence emergence (501–509), flowering (610–619) and capsule development (710), rely on either rainfall or irrigation. Hence, irrigation during critical stages can positively affect tiller production, panicle development and fruit set.

Vegetative bud development (017–019) and side shoot/tillering (principal growth stage 2) are the optimum stages for providing balanced nutrition, which results in the production of more tillers, which has a direct impact on the production of more panicles, ultimately increasing the yield. Tiller production increases with the onset of the monsoon, and peak flowering and fruit set are seen during May–August. Hence, the application of fertilisers during May and September is best under rainfed conditions (Pattanshetty & Nusrath, 1973). Under irrigated conditions, tiller production and panicle initiation are observed throughout the year; therefore, fertilisers can be applied in split doses (Krishnakumar & Potty, 2002).

The newly emerging tillers (principal growth stage 2) in cardamom are infected by shoot flies, developing shoots (301–309) are affected by shoot borers, capsules (710–719) are damaged by capsule borers. Cardamom thrips (*Sciothrips cardamomi* Ramakrishna) causes 30–90% capsule damage, and estimated crop loss in major cardamom producing countries is 48% (Gopakumar & Chandrasekhar, 2002; Dharmadasa et al., 2009; Global Agricultural Information Network, 2014). It damages the panicles, flowers (501–619) and capsules (710–719). This infestation leads to premature flower and capsule drop, and the developed capsules have scab formation on the surface (Jacob et al., 2020). This leads to poor quality capsules and lower market prices. Effective pest management strategies at these stages are crucial to minimise yield and quality losses.

Cardamom is a cross-pollinated crop and honeybees are the major pollinators. The application of pesticides during the peak flowering stage affects pollinators. Thus, knowledge of the flowering stages will help in scheduling plant protection measures.

The colour of the processed produce is an important factor in the consumer market. Green capsules fetch higher prices on the market. Along with the green colour of the capsule, seed maturity is very important to maintain the good quality of the produce. Hence, harvesting the capsules at 810 stage is very important; if the capsules reach 819 stage these capsules will split open during drying and the colour of the capsules turns yellowish.

Understanding the phenology of flowering will help crop improvement programmes through hybridisation. Observing the panicles during 504–617 stages may provide the required number of flowers for hybridisation. As these stages occur during the cool season of the year, there is a higher chance of effective pollination, fertilisation and fruit set.

Cardamom is a very important spice crop that responds very well to nutrition application and is affected by pests and diseases. Understanding the phenological growth stages with specific codes will help in adopting good agricultural practices. In addition, these codes will help exchange information among researchers in different parts of the world. The assigned BBCH scale will help in assessing the impact of climate change on a particular phenological stage.

CONFLICT OF INTEREST STATEMENT

Authors have declared that no competing interests exist.

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