6 Harmonious Phenological Data: A Basic Need for Understanding the Impact of Climate Change on Mango

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Abstract

Uniformly collated phenological data set is the most important requirement for developing climate change impact models for mango. Consistently collected phenological records directly indicate the effect of change in climatic parameters by depicting shifts in phenological events. Recording of consistent data pertaining to phenophases as a function of time serves as critical input for working out integrated interaction of interannual variability, spatial differences and climate variability impacts. In general, uniform qualitative data recording is difficult in mango due to variations in plant growth and development under diverse climatic fluxes occurring in subtropical to tropical regions. Major observed effects of climate change on mango include early or delayed flowering, multiple reproductive flushes, variations in fruit maturity, abnormal fruit set and transformation of reproductive buds into vegetative ones. These critical phenophase-dependent events require supporting quantitative data

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representing behaviour of sufficient number of shoots within a tree for objective analysis of factors influencing them. For monitoring the phenophase dynamics, use of extended BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) scale developed for mango helps in monitoring the phenology by employing uniform methodology over same or different locations with the description of each phenophase in mango as distinctly classified by adopting numerical code. A manual to elucidate the methodology for general users has been developed with the help of pictorial representation of phenophases along with corresponding scores, analysis, depiction of results and interpretation for uniform data recording, and this can be downloaded from http://offseasonmango.cishlko.org/phenology.pdf.

6.1 Introduction

Climate is one of the most important factors controlling growth, yield and success of mango orcharding in a variety of ways. It is evident that natural systems are changing due to changing global climate in the timings of phenological events. Among all the studies and evidence on changing natural ecosystems considered by the IPCC third assessment report (IPCC TAR 2001) on climate impacts, major findings come also from changes in phenological events. Growth and flowering behaviour around the world has indicated that phenological events have changed in mango; for example, early or delayed flowering, multiple reproductive flushes, variations in fruit maturity, abnormal fruit set and transformation of reproductive buds into vegetative one are becoming common.

Phenology is generally described as observation of the life-cycle phases of plants and their relationship with the environment, especially climatic factors. It involves investigation of the plant responses to seasonal and climatic changes in the habitat. Seasonal changes include variations in temperature, rainfall, precipitation, humidity, wind, duration of sunlight, soil temperature, atmospheric circulation, frost and other life-driving factors. Leaf flush, leaf unfolding, flowering, bud burst and fruit ripening are all examples of phenological events or phenophases. Therefore, phenophases are regulated mainly by climatic factors and to a much lesser extent by inner factors of the organism (e.g. genetic regulation, plant hormones). The basic pattern and its plasticity are genetically determined and then modified by the environment. However, temperature is considered the driving factor determining phenological phases because the commencement of each development period for plant requires certain critical and accumulated temperatures.

6.2 Why Phenology Is Important in Climate Change Studies?

It is now well conceptualized that mango phenology has an important connection to climatic components. Numerous examples are evident, early and delayed flowering, fruit ripening, vegetative flushing and multiple flowering, showing that global warming is significantly changing the phenophase seasonality of mango. Due to its sensitive response to climate, phenology responses of mango can be used as an indicator for environmental monitoring, particularly in detecting climate change. It is possible to model the relationship between phenophases and climatic elements only with the availability of long-term phenological data. Study of changes in the timing of plant phenophases in response to climate warming is important for two reasons. First, it demonstrates that climate change is already happening even in response to the current modest increase in temperature, and second, it indicates the extent of change in natural ecosystems that we can expect in the future. Future response of mango to a changed climate can only be predicted by exploring how the crop responded to climate in the past. The use of phenology as a sensitive bioindicator presupposes quantitative analysis of changes in phenological time series and a known relationship with temperature or a comparable change in corresponding temperature series over time.

6.2.1 A Brief History of Phenology

Phenology is an ancient scientific discipline, the history of which dates back to the time of the hunter-gatherers. Monitoring seasonal natural events such as the date of spring blooming of a particular plant species is a centuries-old practice. Keeping records of plant phenology was both a hobby and a tradition for natural historians in many countries. Phenological calendars were used by the ancient Chinese and the Romans to guide agricultural operations, as well in the UK and Japan. Some Chinese phenological series stretch back to the sixteenth century or earlier. In Britain, the long history of recording phenological observation goes back at least 250 years, with the oldest records dated 1703. The systematic collection of phenological records in Britain started in 1736 when Robert Marsham, near Norwich, began to collect 'indicators of spring', particularly flowering, leafing and bird migration dates. Five generations of the Marsham family recorded phenological observations at their estate from 1736 through to 1958, forming the longest phenological record by one family in the world. The Marsham phenological records were related to long-term climate records. Carolus Linnaeus and Robert Marsham now share the honour of being considered the 'fathers' of modern plant phenology.

After the 1990s phenological research gained momentum in the context of research into global change, and a large number of research findings were published on the impacts of climate change on phenological events. As a result some nature-based organizations shifted their focus and deployed their efforts to phenological research. Due to increased research interest in global environmental change and interannual climatic variability, long-term phenological data are becoming essential inputs to climate models. Phenological modelling plays a prominent role in regional ecosystem simulation models and atmosphere general circulation models. Phenological records and models are used in agricultural production, integrated pest- and invasive-species management, drought monitoring, biodiversity, forestry, wildfire risk assessment and treatment of pollen allergies. Therefore, phenology has recently developed rapidly and globally as an environmental science discipline.

6.3 Uniform Phenological Monitoring Methodology for Mango

Uniformly collated phenological data set is the most important requirement for developing climate change impact models for mango. Consistently collected phenological records directly indicate the effect of change in climatic parameters by depicting shifts in phenological events. Recording of consistent data pertaining to phenophases as a function of time serves as critical input for working out integrated interaction of interannual variability, spatial differences and climate variability impacts. In general, uniform qualitative data recording is difficult in mango due to variations in plant growth and development under diverse climatic fluxes occurring in subtropical to tropical regions.

To study the phenological behaviour of the mango in an easy and quick way with more precision, understanding of the methodology for recording and analysis of the data can be of prime importance. Although, some manuals are available to study the phenological behaviour of the forest plants such informative literature customized for mango is lacking. Therefore, for better understanding of the principle and application, need for a manual was felt which can provide consistent methodology to collect high quality, harmonized and comparable phenological data on mango.

Few scales were developed to study the mango phenology are available [Fleckinger's scale (1948), Aubert and Lossois's scale (1972)], but the most simple and significant scale for mango is BBCH (BBCH = Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) scale modified by Hernandez et al. (2011) and Rajan et al. (2011) for mango. A study was carried out to signify the application and validity of the data collected by employing modified BBCH scale at CISH, Lucknow, and the methodology developed for interpretation and presentation of data is described in brief in the manual (Rajan et al. 2012).

6.3.1 Description of the Modified BBCH Scale

The modified scale covers the entire developmental cycle of mango and is subdivided into eight clearly recognizable and distinguishable principal growth stages out of 10 of general BBCH scale. Each principal growth stage is classified into secondary stages which describe points in time or shorter developmental intervals in the major growth stage. This scale starts with bud development (stage 0) and terminated at maturity of fruit (stage 8). In addition to this, the most important phase of plant growth and development, i.e. senescence (stage 9), is described in the modified BBCH scale for mango. The dried/dead shoots, barren panicle and dried/dropped-off panicle are covered under this principal growth stage. The secondary stages are numbered 0–9 that describes related percentile stages of growth. Several mesostages (1 to n) are used to describe the different vegetative and floral flushes during season for coding bud, leaf and shoot development. Therefore, a list of phenological stages of mango can be made in ascending order by sorting codes into numerical order (Table 6.1). As the individual phases of phenological phenomena occur, assessments need should be repeated until the phase is completed. In principle, all phenophases are of interest for phenological monitoring. However, from practical point of view (e.g. financial input, ease and reliability of the monitoring, wide comparability, compatibility with research objectives), it is necessary to concentrate on a limited set of phenophases. The important stages for mango may be considered as 010, 011, 019, 110, 119, 319, 510, 511, 513, 610, 615, 619, 701, 709 and 801. This may be further modified according to one's need to economize the recording of data without loss of available required information.

6.3.2 Criteria for Selection of the Trees

The trees to be assessed should be selected from those orchards which have grown under good management practices. Random sampling should be done for selection of the trees for the assessment. The number of trees to be selected for phenological monitoring depends on the conditions of trees and availability of human resources. All shoots should be numbered and tagged. If there is an insufficient number of shoots, additional trees should be selected from the orchards as good visibility of the selected shoot is necessary. Trees being used for leaf/bud/shoot sampling should not be included. The same part of the tree should be considered for subsequent phenological observations throughout the year as well as for subsequent years.

6.3.3 Frequency of Observations

The frequency of observations depends on the season and objective of the research. A frequency of at least once a fortnight during the growing period is recommended. The minimum required frequency is once a week during the critical phases, but daily observation is the optimum for studies specific to certain phenophases requiring short period for completion. There is no requirement of any kind of equipment and observations should be recorded manually by technically sound persons. As accuracy of the phenological

Table 6.1 Modified BBCH scale for mango (Rajan et al. 2011)

Principal Growth Stage	Code	Description
0 Bud development		
First vegetative flush	010	Dormancy: leaf buds are closed and covered with green or brownish scales
	011	Beginning of leaf bud swelling: bud scales begin to separate
	013	End of leaf bud swelling: scales completely separated, light green buds emerged
	017	Beginning of bud break: light green to dark coppery tan leaf tips just visible
	019	Bud break: light green to dark coppery tan leaf tips visible 5 to 10 mm above bud scales
Second vegetative flush	020	Dormancy: leaf buds are closed and covered with green or brownish scales
	021	Beginning of leaf bud swelling: bud scales begin to separate
	023	End of leaf bud swelling: scales completely separated, light green buds emerged
	027	Beginning of bud break: light green to dark coppery tan leaf tips just visible
	029	Bud break: light green to dark coppery tan leaf tips visible 5 to 10 mm above bud scales
1 Leaf development		
First vegetative flush	110	Leaf tips more than 10 mm above bud scales
	111	First leaf unfolded
	115	More leaves unfolded: petioles visible
	119	All leaves completely unfolded and expanded
Second vegetative flush	120	Leaf tips more than 10 mm above bud scales
	121	First leaf unfolded
	125	More leaves unfolded: petioles visible
	129	All leaves completely unfolded and expanded
3 Shoot development		
First vegetative flush	311	Beginning of shoot growth: axis of developing shoots visible, about 10 % of final length
	312	Shoots about 20 % of final length
	315	Shoots about 50 % of final length
	319	Shoots about 90 % of final length
Second vegetative flush	321	Beginning of shoot growth: axis of developing shoots visible, about 10 % of final length
	322	Shoots about 20 % of final length
	325	Shoots about 50 % of final length
	329	Shoots about 90 % of final length
5 Inflorescence emergence		
Principal flowering	510	Buds closed and covered with green or brownish scales
	511	Beginning of bud swelling, scales begin to separate
	513	Bud burst: first floral primordial just visible, panicle development begins
	515	Flowers are visibly separated, secondary axes begin to elongate
	517	Secondary axes elongated, flower buds are swollen and first light green to crimson petal tips visible in some flowers. In mixed panicles, leaves have reached final length
	519	End of panicle development: secondary axis fully developed, many flowers with green to crimson petal tips visible and some opened, leaves fully developed in case of mixed panicles

(continued)

Table 6.1 (continued)

Principal Growth Stage	Code	Description
Secondary flowering	520	Axillary flower buds of the apical dome are closed and covered with green or brownish scales
	521	Beginning of bud swelling, scales begin to separate
	523	Bud burst: first floral primordial just visible, panicle development begins
	525	Flowers are visibly separated, secondary axes begin to elongate
	527	Secondary axes elongated, flower buds are swollen and first light green to crimson petal tips visible in some flowers. In mixed panicles, leaves have reached final length
	529	End of panicle development: secondary axes fully developed, many flowers with green to crimson petal tips visible and some opened, leaves fully developed in case of mixed panicles
6 Flowering		
Principal flowering	610	First flowers open
	611	Beginning of flowering: 10 % of panicle flowers open
	613	Early flowering: 30 % of panicle flowers open
	615	Full flowering: more than 50 % of panicle flowers open
	617	Flower fading, majority of petals fallen or dry
	619	End of flowering, all petals fallen or dry, fruit set
Secondary flowering	620	First flowers open
	621	Beginning of flowering: 10 % of panicle flowers open
	623	Early flowering: 30 % of panicle flowers open
	625	Full flowering: more than 50 % of panicle flowers open
	627	Flower fading, majority of petals fallen or dry
	629	End of flowering, all petals fallen or dry, fruit set
7 Fruit Development		
Main season fruit development	711	Fruits at 10 % final size, styles still visible, beginning of physiological fruit drop
	713	Fruits at 30 % of final size, end of physiological fruit drop
	715	Fruits at 50 % of final size
	719	Fruit at standard cultivar size, shoulders fully developed, flesh creamy green in colour
Second season fruit development	721	Fruits at 10 % final size, styles still visible. Beginning of physiological fruit drop
	723	Fruits at 30 % of final size, end of physiological fruit drop
	725	Fruits at 50 % of final size
	729	Fruit at standard cultivar size, shoulders fully developed, flesh creamy green in colour
8 Maturity of fruit		
Main season fruit development	810	Physiological maturity: fruit fully developed, flesh creamy green in colour
	811	Beginning of skin colour change
	819	Fruit colour fully developed, fruit ripe for consumption with correct firmness and typical taste
Second season fruit development	820	Physiological maturity: fruit fully developed, flesh creamy green in colour
	821	Beginning of skin colour change
	829	Fruit colour fully developed, fruit ripe for consumption with correct firmness and typical taste
9 Senescence		
Principal vegetative flush/ flowering	911	Barren panicle
	916	Dried shoot, dried or dropped panicle
Second vegetative flush/flowering	921	Secondary flowering: barren panicle
	926	Dried shoot, dried or dropped panicle

data depends on the degree of precision intended by the user, field staff should be trained. A photo guide with almost all phenological stages for mango tree made available for this purpose (Fig. 6.1).

6.4 Data Analysis and Interpretation

The present investigation is based on the work carried out at five diverse eco-geographical locations of Lucknow (subtropics, hot subhumid (dry) ecoregion), Bangalore (Central Karnataka Plateau, hot moist semiarid), Kanyakumari (hot subhumid to semiarid ecoregion), Medak (hot semiarid ecoregion) and Dapoli (West Coast Ghat region) by collecting phenological data and analysing them with the help of BBCH scale developed for mango. The observations recorded on the basis of the BBCH scale are uniform and describe all the growth and developmental stages of mango but generates a large data set and unmanageable for manual interpretation. Thus, the phenophases of selected shoots are summarized on the basis of per cent shoots under particular stage at a specific time. The value indicated the proportion of phenophases and total number of selected shoots (Table 6.2). This interpretation of the data confers the condition of the whole tree.

Phenological data collected on mango trees with the help of BBCH scale generated a large data set, and manual interpretation was difficult. The phenophases of selected shoots were summarized on the basis of per cent shoot under particular stage at a specific time out of total number of selected shoots. BBCH scale-based data is depicted in the form of line graph for identifying phenological stages with highest score at each standard week (Fig. 6.2a). This indicates changes occurring among different phenophases for the identified shoots during particular period and can identify the occurrence of the most frequent stage by viewing the graphical representation. The occurrence of the phenophases was correlated with the prevailing temperature and rainfall (Fig. 6.2b). Brief description of the analysed data represented in the Fig. 6.2a has showed the following transition pattern of phenophases in mango:

1. The stage 010 was recorded with highest percentage in standard week 33 and increased up to 73.3% in standard week 36 indicating rapid growth of shoots. Thereafter, per cent of shoots at stage 010 became constant from standard week 46–51 indicating cessation of growth during the period. From standard week 52, the vegetative growth started and frequency of stage 010 increased. The increment in the percentage of shoots having stage 010 indicated the initiation of vegetative growth.
2. During standard week 33, stage 916 recorded 16.7% as compared to other phenological growth stages. Up to standard week 35, the rise in percentage of shoots in stage 916 indicated the transition of stages 911–916. The constant frequency indicated no further growth in shoots at stage 916 or drying of the shoots.
3. The high degree of variation in percentage of shoots related to principal growth stages, viz. vegetative bud, leaf and shoot development, was observed due to simultaneous transition of the stages during standard week 33–42 and 4–24. The longer and shorter duration between stages 010 and 319 indicated the slow growth and rapid growth of shoots from standard week 33–42, respectively.
4. The stages indicating growth in inflorescence were observed from standard week 3 and continued till standard week 12. The stages 511 (initiation of inflorescence) and 517 (light green to crimson petal tips visible in some flowers) were recorded from standard week 3–11 and 10–12, respectively.
5. The stage 619 (fruit set) was observed between standard week 12 and 16.
6. The stages for fruit development (701–709) were recorded during standard weeks 16–24.
7. The stage 911 in standard weeks 12–16 indicated the existence of barren panicles due to drying or dropping of flowers from the panicles, while in later standard weeks such as from week 17 and onwards, the stage 911 represented the barren panicle after fruit drop.

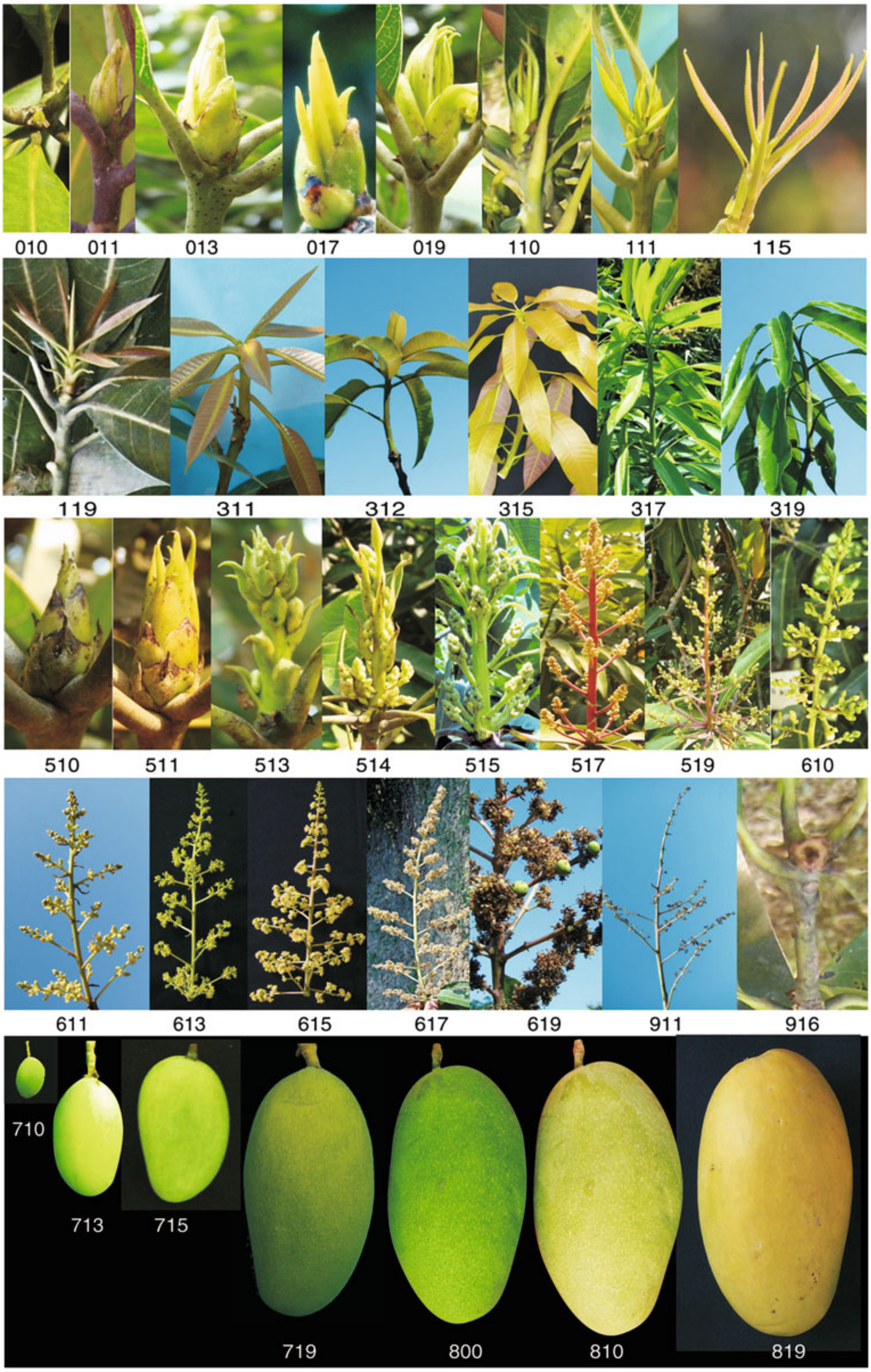

Fig. 6.1 Phenological stages of mango

Table 6.2 Percentage of shoots (using BBCH scale) under different phenophases during August 2010 to June 2011

Month	Std. wks	10	11	13	17	19	110	111	115	119	311	315	319	510	511	513	515	517	519	617	619	703	705	709	911	916
Aug	33	42	5		10	3.3							15												8.3	17
	34	1.7			3.3		3.3	32	1.7	32			1.7												3.3	22
	35				1.7					1.7	6.7		65													25
	36	73	1.7				1.7						3.4													20
Sep	37	1.7	1.7		3.3	45	17	10					3.4													18
	38	1.7					1.7			22	52		3.4													20
	39	68										1.7	8.4													22
	40		1.7		6.7	8.3		1.7		57			3.4													22
Oct	41							3.3		13			62													22
	42	63	3.3		1.7						6.7		12													13
	43	3.3	13		67	3.3																				13
	44							5		78																13
Nov	45									20	1.7		65													13
	46	55	6.7								5		22													12
	47	55	6.7								5		22													12
	48	55	6.7								5		22													12
Dec	49	55	6.7								5		22													12
	50	55	6.7								5		22													12
	51	55	6.7		1.7						5		22													10
	52	58						1.7			3.3		22													15
Jan	1	58									5		22													15
	2	58									3.3		23													15
	3	58	1.7								1.7	1.7	20	1.7	1.7											13
	4	57			1.7					3.3			25	5	1.7											6.7
Feb	5	47	13							1.7	3.3		20	6.7	1.7											6.7
	6	23	30	10	1.7						3.3		13	3.3	6.7	1.7										6.7
	7	17	17	30	3.3	3.3							3.3	12	5	5										5
	8	17	3.3	20	10	5		1.7	1.7				3.3	12	12	8.3										6.7
Mar	9	15	3.3	18	3.3		1.7	5					1.7	5	18	20	3.3									1.7
	10	12		1.7	1.7	10	1.7			12			1.7		20	6.7		32								1.7

(continued)

Table 6.2 (continued)

Month	Std. wks	10	11	13	17	19	110	111	115	119	311	315	319	510	511	513	515	517	519	617	619	703	705	709	911	916
	11	10	1.7	3.3				1.7		27			1.7		1.7	3.3	1.7	45	3.3							
	12	5		3.3	1.7					3.3	12		17					3.3	1.7	25	23				3.3	1.7
April	13	13		1.7	1.7		1.7				3.3	1.7	18						1.7	6.7	38				6.7	5
	14	28		3.3	3.3	6.7				1.7	1.7	1.7	3.4								32				13	3.3
	15	18	6.7	3.3	1.7	3.3		1.7	1.7	1.7	5		6.7								30				12	6.7
	16	10		1.7	3.3	8.3		3.3	1.7	8.3	5		8.3							1.7	27				12	10
May	17	13		3.3				1.7		12	15		8.4							1.7			6.7	1.7	22	8.3
	18	25								1.7	13	1.7	17								1.7	3.3	3.3	3.3	22	8.3
	19	40	1.7								1.7		17									1.7	5	3.3	18	12
	20	53	1.7								5		5										5	5	10	15
June	21	65									3.3		3.3										1.7	8.3	6.7	12
	22	58		6.7	1.7	1.7					3.3													10	6.7	12
	23	40	13	6.7	1.7	1.7					3.3	1.7												10	6.7	15
	24	37			3.3	1.7		1.7		18	3.3		3.3											8.3	6.7	17

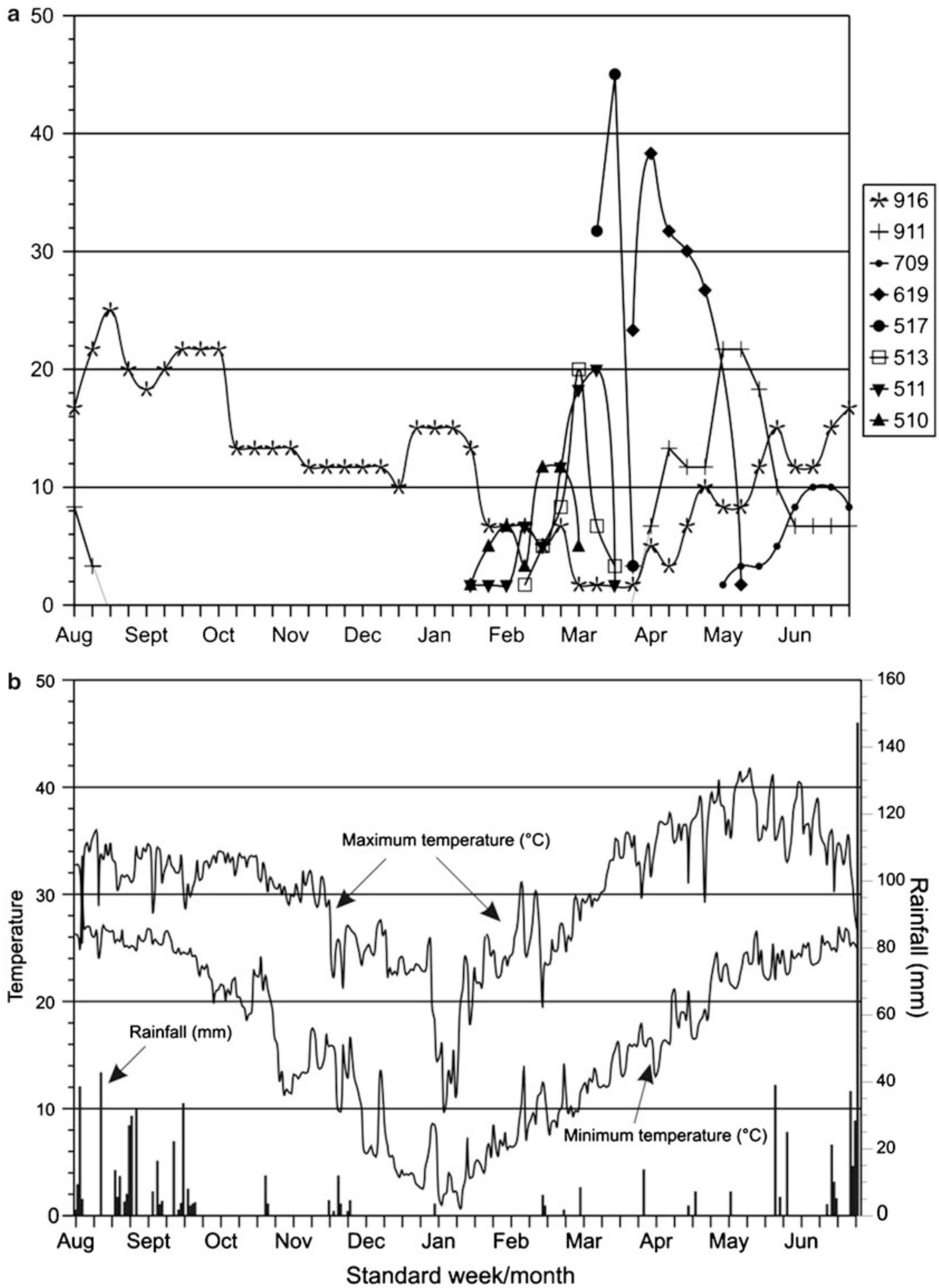

Fig. 6.2 Percentage of shoots under different phenophases (**a**) and weekly meteorological data (**b**) during August 2010 to June 2011

Table 6.3 Timing of important phenophases under different agro-ecologies

Phenophases	CISH, Lucknow	IIHR, Bangalore	DBSKKV, Ratnagiri	APHU, Medak	FRS, Kanyakumari
510	2nd week of Jan	1st week of Jan	3rd week of Oct	1st week of Jan	2nd fortnight of Dec
513	4th week of Jan	3rd week of Jan	1st week of December	3rd week of Jan	2nd fortnight of Dec
610	2nd week of March	2nd week of Feb	2nd week of December	4th week of Feb	4th week of Jan
615	3rd week of March	3rd week of Feb	1st week of Jan	1st week March	1st fortnight of Feb
619	4th week of March	1st week of March	3rd week of Jan	3rd week of March	2nd fortnight of Feb
709	1st week of July	2nd week of April	4th week of March	4th week of May	1st week of May
801	2nd week of July	3rd week of April	1st week of April	3rd week of June	2nd week of May

On the basis of analysed data, the timing of different phenophases was recorded for all the ecological locations which are summarized in the following Table 6.3.

6.5 Need for Online Mango Phenology Network

The UK Phenology Network (UKPN) coordinated by the Woodland Trust and the Centre for Ecology and Hydrology was started in 1998 with the aim of creating a large-scale network of phenology recorders and to search for and preserve historical data. Currently there are more than 20,000 registered volunteer recorders throughout the UK who have already recorded over one million observations from both plants and animals.

The experiences of the UK Phenology Network revealed that it is possible to communicate and disseminate climate change issues to the general public effectively and that phenology has shown itself capable of reconnecting people with nature. Thus, there is a need for developing National Online Mango Phenology Network to bring together scientists, government agencies, non-profit groups, educators and students to monitor the impacts of climate change on mango in India. The network will also harness the power of people and the Internet to collect and share information on phenology by providing researchers with far more data than they could collect alone for developing strategies to reduce the vulnerabilities of mango production to weather dynamics.

6.6 Implications for Impacts of Climate Change on Phenology of Mango

There may be very little study on the impacts of climate change on the phenology of mango, and studies carried out in these areas are either fragmentary or inconclusive. It is now evident that delaying or advancing of flowering is happening and extreme weather events and climate variability are magnifying it. Delay or advance of the arrival of summer, rainy and winter season may disrupt the natural rhythm or synchrony of the ecosystems. It is interesting that some of the newspapers also report about earlier flowering of mango in several parts of Asia. The long-term implications of changes in the phenology of mango may be profound for different ecosystem in mango growing areas of the world. Long-term data are generally required to find out fingerprint of climate change. Though it is already late, there is need to start immediately to collect phenological data every year from different agro-ecological zones which will be an important source for interpreting climate signals from those data. On the other hand, availability of climatic data, e.g. air temperature, rainfall, sea surface temperature and soil temperature, will form a basis for understanding of differential flowering behaviour of mango under different ecologies. For this purpose, both climatic data and phenological data are required to detect climate change trends.

Thus, there is a need of National Online Mango Phenology Network to collect the phenological data under diverse agro-ecological conditions in India to bring together scientists, government agencies, non-profit groups, educators and students to monitor the impacts of climate change on mango. The network will also harness the power of people and the Internet to collect and share information on phenology by providing researchers with far more data than they could collect alone for developing strategies to reduce the vulnerabilities of mango production to weather dynamics.

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