PHENOLOGICAL BEHAVIOUR AND DEVELOPMENT OF FRUIT YIELD PREDICTION MODELS IN *Pongamia pinnata* (L.) Pierre UNDER PUNJAB CONDITIONS

Thesis

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
in
FORESTRY
(Minor Subject: Agricultural Meteorology)

By

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(L-2019-H-163-M)

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CERTIFICATE I

This is to certify that the thesis entitled **"Phenological behaviour and development of fruit yield prediction models in *Pongamia pinnata* (L.) Pierre under Punjab conditions"** submitted for the degree of M.Sc., in the subject of **Forestry** (Minor subject: **Agricultural Meteorology**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Amjed K E (L-2019-H-163-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE – II

This is to certify that the thesis entitled, **"Phenological behaviour and development of fruit yield prediction models in *Pongamia pinnata* (L.) Pierre under Punjab conditions"** submitted by **Amjed K E (L-2019-H-163-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.**, in the subject of **Forestry** (Minor subject: **Agricultural Meteorology**) has been approved by the Student's Advisory Committee along with the External Examiner after an oral examination on the same.

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ABSTRACT

The study on "Phenological behaviour and development of fruit yield prediction models in *Pongamia pinnata* (L.) Pierre under Punjab conditions" was carried out at the main campus, Punjab Agricultural University, Ludhiana and road side plantations, Hambran road, Ludhiana, respectively during 2020-21. The study consisted of two experiments. In the first experiment, phenological data from ten selected *Pongamia pinnata* trees were collected for one complete year (March 2020 to February 2021). The study revealed that in *Pongamia pinnata,* leaf bud bursting occurs twice a year, i.e., in early May when the day length and temperature are high, and in early August after the monsoon season has begun. The initiation of flowering with leaf emergence during the dry period promotes a higher rate of fruit setting due to maximum pollinator availability and activity. The late maturation in *P. pinnata* indicates its independence from rain. In the second experiment, fully ripened fruits were taken from sixty trees of various diameter classes, and various response models were employed to determine the best fit to predict the fruit biomass with respect to DBH. The results clearly indicated that the polynomial function is best suited for estimating fresh fruit biomass based on DBH in *Pongamia pinnata.*

Keywords: Pongam, phenology, fruit biomass, DBH, allometric

Signature of Major Advisor **Signature of Student**

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ਮੌਜੂਦਾ ਅਧਿਐਨ "ਪੰਜਾਬ ਦੇ ਹਲਾਤਾਂ ਅਧੀਨ ਸੁਖਚੈਨ ਦੇ ਫ਼ਲ ਦੇ ਝਾੜ ਦਾ ਅਨੁਮਾਨ ਲਗਾਉਣ ਲਈ ਮਾਡਲ ਦਾ ਨਿਰਮਾਣ ਅਤੇ ਫਿਨੋਲੋਜੀਕਲ ਵਤੀਰੇ ਦੇ ਅਧਿਐਨ" ਸਿਰਲੇਖ ਅਧੀਨ ਪੰਜਾਬ ਐਗਰੀਖਲਚਰਲ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ ਦੇ ਮੁੱਖ ਕੈਂਪਸ ਅਤੇ ਹੰਬੜਾਂ ਰੋਡ ਦੇ ਕੰਡੇ ਤੇ ਲੱਗੇ ਰੁੱਖਾਂ ਉਪਰ 2020-21 ਦੌਰਾਨ ਕੀਤਾ ਗਿਆ। ਅਧਿਐਨ ਦੌਰਾਨ ਦੋ ਤਜ਼ਰਬੇ ਕੀਤੇ ਗਏ। ਪਹਿਲੇ ਤਜ਼ਰਬੇ ਦੌਰਾਨ, ਪੂਰੇ ਸਾਲ (ਮਾਰਚ 2020 ਤੋਂ ਫਰਵਰੀ 2021) ਲਈ ਸੁਖਚੈਨ ਦੇ ਦਸ ਰੁੱਖਾਂ ਦੇ ਫਿਨੋਲੋਜੀਕਲ ਆਂਕੜੇ ਦਰਜ ਕੀਤੇ ਗਏ। ਅਧਿਐਨ ਦੇ ਨਤੀਜਿਆਂ ਤੋਂ ਪਤਾ ਚੱਲਿਆ ਕਿ ਸੁਖਚੈਨ ਵਿੱਚ, ਪੱਤਾ ਅਤੇ ਕਲੀ ਸਾਲ ਵਿੱਚ ਦੋ ਵਾਰ ਫੁੱਟੀ ਹੈ - ਮਈ ਦੇ ਸ਼ੁਰੂਆਤ ਵਿੱਚ ਜਦੋਂ ਦਿਨ ਵੱਡੇ ਹੁੰਦੇ ਹਨ ਅਤੇ ਤਾਪਮਾਨ ਜ਼ਿਆਦਾ ਹੁੰਦਾ ਹੈ ਅਤੇ ਮਾਨਸੂਨ ਤੋਂ ਬਾਅਦ ਅਗਸਤ ਦੇ ਸ਼ੁਰੂਆਤੀ ਦਿਨਾਂ ਵਿੱਚ। ਖੁਸ਼ਕ ਅੰਤਰਾਲ ਦੌਰਾਨ ਫ਼ੁੱਲ ਪੈਣ ਅਤੇ ਪੱਤੇ ਦੇ ਨਿਕਲਣ ਕਾਰਨ ਫ਼ਲਾਂ ਦੀ ਮਿਕਦਾਰ ਜ਼ਿਆਦਾ ਹੋਈ ਕਿਉਂਕਿ ਇਸ ਦੌਰਾਨ ਪਰਾਗਕਣ ਉਪਲਬਧਤਾ ਅਤੇ ਗਤੀਵਿਧੀ ਸਭ ਤੋਂ ਵਧੇਰੇ ਸੀ। ਸੁਖਚੈਨ ਦੇ ਦੇਰੀ ਨਾਲ ਤਿਆਰ ਹੋਣ ਤੋਂ ਇਹ ਪਤਾ ਲੱਗਿਆ ਕਿ ਵਰਖਾ ਦਾ ਇਸ ਉਪਰ ਕੋਈ ਪ੍ਰਭਾਵ ਨਹੀਂ ਸੀ। ਦੂਜੇ ਤਜ਼ਰਬੇ ਵਿੱਚ, ਸੱਠ ਦਰਖਤਾਂ ਤੋਂ ਵੱਖ-ਵੱਖ ਵਿਆਸ ਦੇ ਚੰਗੀ ਤਰ੍ਹਾਂ ਪੱਕੇ ਹੋਏ ਫ਼ਲ ਲਏ ਗਏ ਅਤੇ DBH ਦੇ ਲਿਹਾਜ਼ ਨਾਲ ਫ਼ਲ ਦੇ ਜੈਵਿਕ ਮਾਦੇ ਦਾ ਸਹੀ ਅਨੁਮਾਨ ਲਗਾਉਣ ਲਈ ਵੱਖੋ-ਵੱਖਰੇ ਮਾਡਲਾਂ ਦੀ ਵਰਤੋਂ ਕੀਤੀ ਗਈ। ਅਧਿਐਨ ਦੇ ਨਤੀਜਿਆਂ ਤੋਂ ਇਹ ਸਪਸ਼ਟ ਹੋਇਆ ਕਿ ਸੁਖਚੈਨ ਵਿੱਚ DBH ਦੇ ਅਧਾਰ ਤੇ ਤਾਜ਼ਾ ਫ਼ਲ ਦੇ ਜੈਵਿਕ ਮਾਦੇ ਦਾ ਅਨੁਮਾਨ ਲਗਾਉਣ ਲਈ ਪੋਲੋਨੋਮਓਿਲ ਫ਼ੰਕਸ਼ਨ ਸਭ ਤੋਂ ਵਧੀਆ ਸੀ।

ਮੁੱਖ ਸ਼ਬਦ: ਪੋਂਗਮ, ਫਿਨੋਲੋਜੀ, ਫ਼ਲ ਦਾ ਜੈਵਿਕ ਮਾਦਾ, DBH, ਐਲੋਮੇਟ੍ਰਿਕ

ਪ੍ਰਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ **ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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CHAPTER I

INTRODUCTION

Pongamia pinnata (L.) Pierre, a member of the family Leguminosae, is a medium-sized, evergreen or briefly deciduous, multipurpose tree with a broad crown which is often planted as a shade tree, along roadsides, and along stream and canal banks. It is commonly known as pongam in India. Pongam attains a height of up to 20 m and a DBH of more than 50 cm (Troup 1921). Pongam originated in India and is found throughout tropical Asia and Australia. The species is found naturally along India's coasts and riverbanks (Arote and Yeole 2010). It can grow on most soil types except dry sands, with an annual rainfall of 500-2500 mm, and a temperature range of 1-38°C (Champion and Seth 1968). This species can withstand drought, waterlogging and minimal frost (Beniwal 2011). It regenerates profusely from seeds in nature under frost condition. The tree has good coppicing power and it gives out root suckers in natural conditions. Wood is not considered as a quality timber, but it is used for a variety of domestic and industrial purposes such as firewood. The leaves have good fodder value as they contain 18% crude protein. Pongam is a tree with a dense network of lateral roots that is used to control soil erosion and to bind sand dunes. It is also capable of fixing nitrogen from the atmosphere. Because pongam can tolerate moderate salinity, it is an excellent candidate for the reclamation of a wide range of wastelands. It is also widely used in the reforestation of marginal lands and in social forestry activities.

Phenology is the science concerned with periodic biological events in the animal and plant world which are influenced by climate and weather. The main purpose of phenological study is to compile annual data on vegetative and reproductive phenophases with climatological observations in the context of changes in abiotic and biotic forces, and the connection between phases of the same or separate events are all studied (Reichle 1973, Leith 1974). Apart from the rainfall and temperature, the phenology of tropical trees is influenced by the topographical factors like elevation and altitude also. Phenology is an important field of study in many applied science disciplines, such as agriculture and forestry and provides valuable information for the planning and management of meteorologically bound activities (Ruml and Vulic 2005). Because of anticipated global environmental climate change, understanding of tree phenology is quantitatively related to the environment has become even more important. The timing of phenophases of a species can change significantly as a direct response to environmental factors, and this can have greater impacts on the population. Any conservation approach should therefore focus on a comprehensive analysis of plant phenology (Kallarakkal and Renuka 2015).

Leaf phenology research highlights the impact of the environment on plant traits, which has significant consequences for leaf and shoot growth (Reich *et al* 2004). Leaf and flower initiation observed during summer months among most of the tropical trees in India. This appears to be a mechanism to survive in an adverse climatic condition, characterised by a short monsoon season and a long summer season. Analysis of the duration of deciduousness and timing of bud break will help to assess future climate change impacts. The study of phenology also provides better understanding about the effect of environmental pressures on flowering and fruiting behaviour (Zhang *et al* 2006). Temporal variation in flowering time with respect to vegetative phenology influenced by various factors, including winter or summer showers, variation in photoperiod, or summer-induced leaf shedding, results in several flowering behaviours in tropical forests (Borchert *et al* 2002).

The pongam fruit is single-seeded and generally called a pod. Fruiting usually occurs in June, and the number of fruits per bunch varies from 5-6 to 10-15. The development of the pod is divided into three stages – light green, half brown and a dark brown stage. Fruits develop to their maximum size between June and September. The embryo consists of a pair of cotyledons and the accumulation of the storage components stabilizes at the end of maturity, which denotes the harvesting period. Therefore, this study is aimed at recording and analysis of the phenological behaviour of *P. pinnata* in Punjab.

For today's research workers, an ever-growing demand for fuel has been a concern. Researchers have attempted to use plant based oils and their compounds as a fuel in compression ignition engines. Different kinds of plants, like *Jatropha curcus*, *Saemuruba*, *Pongamia pinnata* (karanj), castor, cotton, jojoba, wild apricot, neem, mahua, etc., are available as raw materials in different parts of the country. Among these, because of its easy availability in the wild and high yield, *Pongamia pinnata* is considered as a reliable raw material in biofuel research. Pongam oil has an excellent calorific value and other properties after transesterification process (Bobade and Khyade 2012). Pongam seed oil is widely known as 'Honge oil' and is used as a fuel for cooking and lamps, as a lubricant, water-paint binder, pesticide, insecticide, and in the tanning industry. It is also known for its medicinal properties which is used for treating diseases like tumours, skin diseases, ulcers, and piles. Recent studies also shows that *P. pinnata* contains agents which can treat microbial infection. Pongam seeds contain 30-35% oil and it exhibits similar features of diesel. But, pongam oil needs preheating due to high viscosity (Shrivastava and Prasad 2000). Pongam oil phytoconstituents primarily belong to the group of flavonoids and fixed oils. It is clean, sustainable and non-polluting (Arote and Yeole 2010).

Allometry is a study of the correlation between measurable components/ characteristics of an object and its overall structure (Gayon 2000). In forestry, allometry is employed to estimate and measure the biomass of an individual tree or a part of it including fruits (Maniatis *et al* 2011), height, wood specific density, etc. A model is considered as a simplified representation of reality. Models help to determine the inputs to get the desired output and system sustainability. Allometric models are broadly categorised into linear and non-linear models. Linear models are simple and effortless to use. However, they are not so accurate, while non-linear models are more accurate. Developing fruit yield prediction models in pongam is important as far as oil yield estimation is concerned, as no such models have been developed so far for this species. This study is also aimed at the collection of pongam fruits from various locations in Punjab and the development of fruit yield prediction models for future use.

Therefore, keeping these important considerations in mind, this study was planned with the following two objectives.

i. To study the phenological behaviour of *Pongamia pinnata* under Punjab conditions.

ii. To record the fruit yield in *Pongamia pinnata* and develop prediction models based on DBH under Punjab conditions.

CHAPTER II

REVIEW OF LITERATURE

The task of plant phenology is to watch and record the periodically repeating development stages and to study the regularities and reliance of the annual cycles of development on natural conditions. Phenology provides important data for planning land use and forestry activities, control of forest pest species, control of forest fire, conservation of important tree species, understanding the effects of climate change, studying reproductive biology, etc. The fruit yield prediction models for pongam are not available, but similar studies on various other species of trees, especially horticultural species, are available. Despite a large number of commercially important fruit or oil-yielding species in the forests, very few or no fruit yield prediction models exist for them. Even if prediction models are available, their area of applicability and range of application is uncertain.

2.1 PHENOLOGICAL STUDIES

Phenological studies are very useful for compiling annual data and for the preparation of phenological models, especially for agricultural crops. Knowledge of phenology and floral morphology is essential for conducting studies on breeding systems, particularly pollination studies. Phenological studies of different forest trees have long been studied for the systematic management of plantations and natural forests. The phenological studies of various tree species are widely available. However, phenology, in particular of *Pongamia pinnata,* is not extensively studied.

2.1.1 Phenological Studies in Forestry

Paul *et al* (1980) studied the phenology of tree and shrub species in tropical wet and dry forests in Costa Rica's lowlands between 1970 and 1973. They examined individuals of 154 tree and shrub species in a wet forest site and 95 species in a dry forest site in Costa Rica for studying changes in leafing, blooming, and fruiting at 4- to 6-week intervals. The wet forest's shrubs were all evergreen. Half of the species continuously produced new leaves throughout the year, though this behaviour was more pronounced in secondary forest species (87%). Leaf production was consistent throughout the year for the entire community. In the dry forest, deciduous trees and shrubs made up about half of the trees and shrubs. Hill forest trees and shrubs produced the most leaves at the start of the wet season, riparian forest trees and shrubs produced the most leaves near the end of the wet season, and secondary forest species continued to leaf throughout the wet season. During the dry season, most trees and shrubs were bare or dormant. The month of February experienced the most leaf loss. In the wet forest, there were no consistent flowering peaks for tree and shrub species, but flowering levels tended to be highest in the first half of each year. Continuous flowering was uncommon among wet forest trees and shrubs, occurring only in a few secondary forest species. The majority of wet forest trees and shrubs (64 per cent) had multiple flowering episodes per year, separated by 3-5 months. Only a few species had a single brief synchronous flowering period. Flowering among dry forest trees and shrubs, on the other hand, followed a distinct seasonal pattern. The riparian forest tree and shrub community had their major flowering at the end of the wet season, whereas the hill forest tree and shrub community had their flowering peaks towards the start of the wet season. The majority of dry forest species bloomed once or twice in a year. But the second half of each year had a weak tendency for maximum fruiting of wet forest shrubs. Most wet forest trees and shrubs had a short period of fruit maturation (4 months), though one species had a fruit maturation time of 27 months. During the study, ten species of wet forest trees and shrubs flowered at least once but did not produce fruit. Tree and shrub communities in the dry forest, hill forest, and riparian forest had two yearly fruit production peaks (February-April and August-September). Almost all trees and shrubs in the dry forest had irregular fruiting and short fruit maturation times. None of the fruits took longer than 12 months to mature.

Reich and Borchert (1982) studied the phenology and seasonal variations in water stress across many *Tabebuia neochrysantha* trees growing at many dry and wet sites in a lowland deciduous forest in Guanacaste, Costa Rica, throughout 1978. The rate of leaf fall during the early dry season was strongly related to the decline in soil moisture and the trees' increasing water stress. Flowering and shoot emergence required recovery from water stress in all cases. Rehydration occurred only after isolated rain showers or irrigation at dry sites and at wet sites, it occurred during prolonged drought, most likely as a result of the decrease in transpiration during leaf fall. Flowering has been observed to occur at any time during the dry season, from the beginning (December) to the end (May). Variability in flowering timing and intensity, as well as leaf fall and shoot emergence, are found to be explained by site-dependent differences in tree desiccation and rehydration rates, in conjunction with year-to-year variation in rainfall timing and intensity. They discovered no indication of additional environmental factors, such as temperature fluctuations during the photoperiod, controlling seasonal development.

Shukla and Ramakrishnan (1982) carried out phenological observations of 122 tree species in subtropical humid seasonal forests in northeast India. Compared to deciduous trees, there were more evergreen trees in the forest. In majority of the species, flowering coincided with leaf fall. Most species produced fleshy fruits during the rainy season. Differences in flowering and fruit types in different genera and species indicated the importance of interaction between animals and plants. Philips and Buckman (1983) studied the phenology and reproductive biology of *Zostera marina* L., a sea grass in Bahia Kino, Cortez Sea, Mexico. The study revealed that all reproductive activities were completed before the lethal upper limit for the species is reached (30°C) and they concluded that this species is a true annual and represents a perfect reaction to high water temperatures.

Ralhan *et al* (1985) examined the phenology of tree components of natural forests in Kumaun, Himalaya, between 350 and 2150 m elevation.. There were more evergreen taxa than deciduous taxa in all forests. With increasing elevation and decreasing summer dryness, the degree of evergreenness increased. The majority of species experienced concentrated leaf drop and simultaneous leafing during the warm-dry season. Approximately, half of the species had multiple leafing. In April, all species bloomed profusely. Wet-season flowering was uncommon. The majority of the species bloomed at the same time. A single peak of fruit maturation occurred in the Sal (*Shorea robusta*) and pine (*Pinus roxburghii*) forests in summer, while a secondary peak occurred in other forests in autumn.

Newton (1988) investigated the vegetation structure and phenology of a moist deciduous forest in Kanha Tiger Reserve, Madhya Pradesh, India. All, 9935 trees (woody plants > 2 m tall) of 63 species were enumerated and their girths were measured within a grid of 0.25 ha quadrats. The dipterocarp Sal dominated the forest (*Shorea robusta*). The majority of the species were uncommon and had clumped distributions within the ‘Sal sea’, while the dispersion of five large canopy trees could not be distinguished from random. An index of phytophase abundance was used to track the phenology of 215 trees from 61 different species over 14 months. Leaf renewal was highly synchronous between and within species, with the majority of it taking place between February and June. There were 55 deciduous species, five semi-evergreen species, and one evergreen species. Between leaf fall and flush, flowering occurred, with fruiting peaked late in the summer and early monsoon.

Bullock and Magallanes (1990) studied the phenology of canopy trees in a Mexican tropical deciduous forest. For 42 months, the phenology of 108 species (1094 trees) was investigated in a tropical deciduous forest in Mexico's Pacific lowlands. The most vigorous leaf expansion occurred in June and July, with the forest canopy being at least 75 per cent full for only 30 per cent of the study period. The species were leafless for several months each year, with a few exceptions. Gradual leaf loss in most species suggested that there were significant inter-and intraspecific differences in growing season length. Peak flowering occurred in June and July. In most cases, flowering lasted less than two months. Closely related species typically flowered at the same time. There was no discernible mode of delay between flowering and dispersal. Peaks in seed dispersal did not have a community mean, but endozoochores differed from other species in seasonality. Most populations reproduced once a year, with sub-annual intervals determined by rainfall anomalies. Many species responses to rain in December or January indicated that their phenology was influenced by water availability, but other species phenology was most likely influenced by photoperiod. The simultaneous flushing and flowering of many species indicated intensive use of stored resources.

Clarke and Myerscoe (1991) recorded the flowering and reproductive stages of the *Avicennia marina* (grey mangrove) in New South Wales, Australia. Individual flowers were protandrous and opened for 2 to 5 days, and a cluster bloomed for 24 weeks. It is found that about four ovules and 16,000 pollen grains are produced per flower. Because of protandry, self-pollination is improbable. But geitonogamy is favoured due to the synchrony of flowering, along with pollinator behaviour. The flowering of individual trees varies greatly from year to year and many trees cannot reproduce annually, even if the populations remain productive every year. Their study shows that the annual propagule supply in the population was ensured by a flexible breeding pattern and the regular reproduction potential of the population.

Bhat (1992) observed the phenological behaviours of tree species in the tropical moist forests of Karnataka, India between 1983 and 1985. The study has shown that there exists a strong seasonal variation in leaf flush, leaf drop and reproduction. Flowering had two peaks (December and March), and fruit ripening had a single peak in May-June, just before the monsoon rains. The leaf ripening time was the shortest, whereas, the fruit ripening time was the longest. Evergreen species blossoms lasted longer than deciduous species. On the other hand, deciduous trees had a longer phenophase of riped fruits than evergreen species.

Hoffm *et al* (1994) studied the phenology and reproductive biology of *Brachylaena huillensis*, a dioecious tree, in Kenyan natural forests. It bloomed twice a year and bears fruit. The flowering was largely influenced by the frequency and amount of precipitation. They produced more male trees than female trees per unit area, and the males produced more flower heads per panicle. The fruit yield was very high, but insects attack up to 80% on the fruit before dispersal was noticed. Reducing the number of individuals under either of the sexes below a certain level can negatively affect the optimal sex ratio needed for sustainable regeneration.

Proenca and Gibbs (1994) studied the pollination biology and breeding systems of eight members of the Myrtaceae family in Brazil, namely *Blepharocalyx salicifolius, Campomanesia pubescens, C. velutina, Eugenia dysenterica, Myrcia linearifolia, M. rhodosepala*, *Psidium firmum*, and *Siphoneugena densifiora*. Those species were studied for their flowering behaviours, like mass flowering and steady-state types. Flowers opened early in the morning and lasted throughout the day. All eight species were bee-pollinated. They recorded buzz-pollination in three species. Pollinator-sharing of *Bombus* spp. Bees were found in four savannah species and pre-dawn pollination was observed in *S. densiflora* by *Ptiloglossa* spp. (Colletidae) and the other two trees had open pollination systems. The three forest species were clearly self-incompatible, whilst three savanna species showed self-compatibility. The remaining two savanna species have proven themselves to be compatible.

According to Dhaila *et al* (1995), deciduous tree species may or may not initiate growth earlier, but they complete shoot growth way sooner than evergreen tree species. Studies in the central Himalayan forests indicated that deciduous species shed their leaves soon after the wet summer or before the onset of the dry season, while the evergreen species carry their leaves throughout the winter, and leaf drop coincides with the onset of dry summer leafing and shoot growth. Ward *et al* (1995) observed that the changes in pod colour from initiation to maturity were caused by chlorophyll breakdown and ethylene synthesis. Maturity has crucial implications in terms of harvesting fruits at the appropriate stage so that the seeds develop excellent qualities.

Devineau (1999) investigated the seasonal patterns and phenological behaviours of savanna woody species in a dry farming system in southwest Burkina Faso. For two years, the leafing, flowering, and fruiting of the 24 prominent tree and shrub species in the Sudanian savannas and fallows near Bondoukuy were investigated from May 1992 to June 1994. Defoliation was generally brief, and leaf flushing, flowering, and fruiting occurred primarily during the dry season. Nonetheless, phenological behaviour differed between species and individuals. A classification based on synchrony/asynchrony and length of the foliation, flowering, fruit setting, and seed dispersion stages allows for the phenological plasticity of species to be compared. From trees to shrubs, species were distributed along a scale of increasing plasticity. On this scale, leguminosae species seemed to be segregated from combretaceae species, with the latter commonly regarded to characterise fallow agricultural systems. These findings add to the body of knowledge about the impact of phylogenetic constraints on the phenological behaviour of Sudanian savanna woody species.

In the Brazilian Amazon, Gribel *et al* (1999) investigated the flowering and fruiting phenology, floal biology, and breeding process of the tree species *Ceiba pentandra*. During the 6-year study period, 17 of the 21 trees studied flowered once or twice. Fruits from the mixed-pollination set just 1.6 per cent of selfed seeds, according to a progeny study using isozyme markers from this self-incompatible tree. The percentage of outcrossed seeds in fruits produced by open-pollination in two neighbouring planted trees that flowered in isolation and simultaneously were estimated to be 91 per cent and 71 per cent, respectively. Since this species has varying degrees of self-fertility, two isolated trees did not set any fruit despite massive flowering, while two others produced large amounts of seed.

Sakai *et al* (1999) conducted the first comprehensive study of general flowering, a phenomenon observed solely in lowland mixed-dipterocarp forests in Southeast Asia. In Sarawak, Malaysia, they researched the reproductive phenology of 576 individual plants, comprising 305 species in 56 families. Observations began in August 1992 and lasted 53 months, covering one episode of a general flowering period. In 1996, out of 527 successful reproductive events over 43 months, 57 per cent occurred during the general flowering period (GFP) of 10 months. Based on the timing and frequency of flowering, they divided 257 species into various flowering types. The most common type (35 per cent) was "general flowering," which only flowered during GFP. Pollination promotion caused by interspecific synchronisation and a lack of climatic cues appropriate for flowering stimulus are two possible triggers for general flowering.

Justiniano and Fredericksen (2000) investigated the phenology of commercially important timber species in a semi-deciduous dry forest in the Lomero area of Santa Cruz, Bolivia, for two years in order to gather biological data for forest management. Monthly observations were made of the flowering, fruiting, and leaf fall of 162 individual mature timber trees from 17 different species. Despite phenological patterns differing from year to year, the majority of the trees were devoid of leaves from June to September, corresponding to the mid to late dry season. The majority of species also blossomed during the dry season. Peak fruiting occurred just before the start of the rainy season, with the majority of species fruiting in August and September of both years. This is also the time of year when the majority of forest harvesting takes place. Improved harvest timing coordination with seed fall will increase with increased light and scarified soils, potentially increasing regeneration success. Except for two species, all had wind-dispersed seeds, highlighting the importance of leaving productive seed trees dispersed throughout this forest. The frequency with which the seeds were produced varied greatly between species. However, when all species were averaged, only about one-third of mature trees produced seeds in either year of this study. As a result, many more seed trees must be retained for most of species than would be required if all trees produced an annual crop of seeds.

Kokkoris and Margarita (2000) investigated the flowering and fruiting phenology of four annual legumes (*Lathyrus uphaca*, *Lathyrus cicevu*, *Scorpiurus muricatus*, and *Cassia sativa*) at the individual and population levels to understand their strategies.. Self-pollination was prevalent for the legume species studied, although cross-pollination was also reported on rare occasions, according to their breeding system. The plant species followed the same trend as most pioneer species, i.e., they reproduce opportunistically. In the ephemeral post-fire environment, this form of reproduction results in reproductive output.

Morellato *et al* (2000) described the vegetative and reproductive phenology in southern Brazil's Atlantic rain forests. They observed the phenological behaviours of trees from two forest types spanning 17 months in four separate locations: premontane forest (Sites I and IV; typical Atlantic rain forest) and coastal plain forest (Sites II and III). All sites experienced a nonseasonal, tropical wet climate, with annual rainfall typically exceeding 2000 mm and no dry season. They used circular statistics to compare the patterns detected among the four different forest sites and to test for the presence (or absence) of seasonal phenological patterns within each site. These forests did not exhibit the expected weakly seasonal phenological patterns. Flowering and leaf flush trends in Atlantic rain forest trees were highly seasonal, peaked at the beginning of the rainy season, and significantly linked with day length and temperature. These findings highlighted the importance of seasonal variation in day length on the phenology of ever-wet forest trees. In all four forests, fruiting phenologies were aseasonal. Flowering trends did not vary among three of the four forest sites evaluated, demonstrating that Atlantic rain forest trees have a consistent flowering pattern.

Carri *et al* (2001) performed field studies and growth chamber experiments in the central valley of California to determine the reproductive potential, flower phenology, seed viability and germination, and overall seed bank longevity of yellow star thistle. Yellow star thistle seed germination correlated with seasonal rainfall in a field experiment. After one growing season, 44 and 39 per cent of pappus bearing and non-pappus bearing seed, respectively, germinated. After two growing seasons, it was estimated that over 97 per cent of the total seeds were removed from the soil seed bank from projected values based on recovered and germinated seed.

Eamus and Prior (2001) carried out study on the ecophysiology of trees in the seasonally dry tropics and focuses on the world's seasonally dry tropical and subtropical woodlands and forests, distinguishing woodlands from forests based on percentage of canopy cover. They described the physiological and structural properties of trees in seasonally dry tropical habitats that determine their water and gas exchange relationships. To explain the patterns of productivity and ecosystem function, these properties must eventually be linked to larger-scale processes. Seasonally dry forests are an important type of vegetation on a global scale. Productivity is rarely hampered by temperature and light availability. However, water can be very limited for a significant portion of the year in the majority of seasonally dry woodlands and forests, but not in all. Deciduous and evergreen species represent opposite ends of a leaf lifespan continuum. They also discussed cost-benefit analyses for savanna tree leaves and mentioned that leaf construction costs can be calculated from detailed investigations of biochemical pathways used during the construction of the principal components of leaves.

Griz and Machado (2001) studied the fruiting behaviour and seed dispersal patterns of plants in the Caatinga, a semi-arid region in northeastern Brazil. Over a year, the fruiting phenology of 42 species with various dispersal modes and life-forms was studied. Animal dispersal was the most commonly observed dispersal mode (36%), followed by anemochory (33%), ballistic dispersal (19%), and barochory (3%). During the rainy season, a greater number of species fruited and zoochorous species predominated, whereas anemochorous species predominated during the dry season. Five different life-forms were observed, and the occurrence of dispersal modes for each of them was discussed. The patterns of life forms, fruiting phenology, and seed dispersal syndromes observed in the Caatinga plant community were similar to those observed in other tropical seasonal ecosystems.

Kikim *et al* (2001) conducted experiments on the phenology of tree species in the subtropical forests of Manipur in north eastern India. From January 1993 to December 1994, phenological characteristics of 32 dominant tree species were studied in forest ecosystems at Kangchup Hills, Manipur. Vegetative and reproductive phenological behaviours in understorey and overstorey tree species were also investigated. In all of the forest sites, the number of evergreen tree species was greater than the number of deciduous tree species. Leaf drop peaked in the cool dry season (January-February) and leaf flushing at the beginning of the warm dry season (March-April), with another peak in the rainy season (August). In April, both overstorey and understorey species had a strong flowering peak. Fruit maturation was at its peak between September and October. Both over and understorey tree species had simultaneous leaf flush and flowering, but understorey tree species fruited one month earlier than overstorey tree species.

Nikkanen (2001) studied flower and fruit phenology in a seed orchard of Norway spruce located in southern Finland, which included 67 clones from northern Finland. The effect of genetic and environmental factors on female and male phenology, as well as reproductive synchronisation, were examined. Flowering times varied by more than three weeks from year to year. The variance was smaller when it was described based on the effective temperature sum. Between the seed orchard and the surrounding natural forests, no phenological reproductive isolation was detected. The flowering times of the various clones tended to overlap in general. In most cases, clonal variations in the phenology of receptivity were statistically significant, but not in pollen shedding. Female phenology had higher broad-sense heritability estimates than male phenology. On the other hand, environmental influences had a greater impact on male phenology. Early pollen shedding and, as a result, better reproductive synchronisation between female and male flowerings were encouraged by broad graft spacing and a graft position that favoured solar radiation on the lower sections of the crown. According to Srimathi *et al* (2001), the colour of fruit has long been thought to be an easier strategy for providing quality seeds in forestry. The size of fruits and seeds has also long been thought to be a significant variable in plant reproductive biology (Khan *et al* 2002).

Sugiura *et al* (2001) investigated the *Cypripedium macranthos* var. rebunenseon for the protection of this endangered orchid on Rebun Island, Hokkaido, Japan. Fruit set was found to be 8.3% at one study site but just 1.2 per cent at another, owing to interference from the many tourists who came to see the flowers. The conservation and management of the lady's slipper orchid were explored as a result of the findings. It was emphasised that there should be less human intervention and that interactions between lady's slipper and its pollinator or other plant species with floral rewards should be maintained. Maues (2002) investigated the reproductive phenology and insect pollinators of the Brazilian nut tree (*Bertholletia excelsa* Humb. & *Bonpl. Lecythidaceae*), a commercially important fruit tree indigenous to the Amazon forests. Medium to large-sized bees are the primary pollinators. According to the findings, *B. excelsa* is a mellitophilous species that relies on pollinator behaviour to produce fruit.

McIntosh (2002) studied the flowering phenology and reproductive performance of two sister species of barrel cacti, *Ferocactus cylindraceus* and *Ferocactus wislizeni*, in the Sonoran Desert near Tucson, Arizona. He discovered that while flowering time does affect individual plant reproductive output, variations in reproductive output are likely to be more closely linked to flower production (which is strongly correlated with plant size) and pollinator-mediated seed production than to the different flowering phenologies of those plants.

Ramirez (2002) analyzed the flower and fruit phenology of 171 plant species from 57 angiosperm families in four habitat types in a Venezuelan Central Plain savanna forest ecosystem. Except for the forest, all habitats showed marked seasonality in flower, unripe fruit, and mature fruit development. Flowering peaked during the rainy season, while fruiting peaked towards the end. Shrubs' mature fruit production peaked during the time of maximum rainfall, while perennial herbs peaked late in the rainy season and annual herbs peaked during the transition between the rainy and dry seasons. In the Venezuelan Central Plain, he discovered that variations in phenological trends in ecosystems were primarily caused by life forms, which encourage a broader distribution of reproductive events in habitats and the overall community.

Rivera *et al* (2002) observed highly synchronous bud break with low inter-annual variation during the late dry season, around the spring equinox, in many conspecific trees of more than 50 species in the semideciduous tropical forests of Argentina, Costa Rica, Java, and Thailand, and in the tropical savannas of Central Brazil. Bud break was 6 months later in the northern and southern hemispheres, but one month earlier in the subtropics than in lower latitudes. These findings suggest that a photoperiod increase of 30 minutes or fewer causes "spring flushing," or synchronous bud break around the spring equinox and weeks before the first rains of the wet season. Spring flushing is common in semideciduous forests, which have a 4-6 month dry season and an annual rainfall of 800–1,500 mm, but it is uncommon in neotropical forests, which have a shorter dry season or lower annual precipitation. In tropical forests with a relatively short growing season, establishing new foliage shortly before the wet growing season is likely to optimise photosynthetic gain.

Schongart *et al* (2002) studied the impact of periodic long-term floods on seasonal tree development by observing the phenology and growth in stem diameter of various tree species with varying leaf-change patterns in Amazonian floodplains over a two-year period. The trees of the functional ecotypes, evergreen, deciduous, and stem-succulent, showed periodic behaviour that was predominantly induced by the flood-pulse. During the terrestrial phase, trees grow rapidly. Flooding caused some or all of the leaves to fall off, resulting in a cambial dormancy of about 2 months and the formation of an annual ring. Studies in tropical dry forests confirmed a strong relationship between phenological development and the water status of the trees, which was heavily influenced by seasonal drought. Except for stem-succulent tree species, a comparison of the phenology and diameter growth of the corresponding ecotypes in floodplain forest and semi-deciduous forest in Venezuela revealed a displacement of at least 2 months in the periodicity. The factors which control phenology and stem diameter growth in stem-succulent trees was still uncertain.

Borchert *et al* (2004) studied the environmental influence on flowering periodicity in tropical dry forests of Costa Rica and Mexico. They examined at the underlying factors which cause substantial difference in flowering periodicity among four tropical dry forests (TDF) and inquired if the ultimate causes of flowering periodicity are climatic periodicity or biotic interactions. The four locations of TDFs in Guanacaste (Costa Rica), Yucatan, Jalisco, and Sonora (Mexico) have a dry season that lasts 5-7 months and are located along an increasing latitude gradient (10-30°N). Individual tree species were assigned to ‘flowering types', which were groups of species with characteristic flowering periods determined by similar combinations of environmental flowering cues and vegetative phenology, to dissect the differences in flowering periodicity observed at the community level. Large differences in the fraction of species and flowering types blooming during the dry and wet seasons, respectively, indicated significant differences in the severity of seasonal drought across the four forests. The flowering of leafless trees in Jalisco's dry upland forests was suppressed during severe seasonal drought and was triggered by the first rains of the wet season. In other forests, many deciduous species flower at different times during the dry season, well before the summer rains, due to leaf dropping, excessive rainfall, or increased day length. The Sonoran TDF has the highest proportion of deciduous species that leaf out during the summer rains and flower when leafless during the dry season. The phenotypic plasticity of flowering periodicity was high in diverse species. Spring flowering on leafless shoots and subsequent summer flushing represent a unique adaptation of tree development to climates with a relatively short rainy season and a long dry season. Seasonal variation in rainfall and soil water availability appears to be the primary cause of flowering periodicity, which is unlikely to have evolved in response to biotic adaptive pressures.

Marques *et al* (2004) explored the phenological patterns of different plant life-forms in a southern Brazilian subtropical forest. Tropical plant phenology is typically associated with clear seasonality of rainfall associated with very different wet and dry seasons. Plant phenology was studied in a subtropical forest with no marked dry season to look for patterns (periodicity), see how phenological patterns differ among life-forms, and to see if phenological cycles are related to climatic variables. From 1996 to 1998, 37 plant species representing four life-forms (trees, shrubs, lianas, and epiphytes) were investigated in an Araucaria Forest remnant in the southern Brazilian state of Parana. Multiple regression and correlation methods were used to establish relationships between phenology and climate in terms of day length, temperature, and rainfall. Most life-forms and phenological phases of plants in this Araucaria forest showed seasonality. Leaf-fall was the most seasonal, peaking during the drier months (April to July). Flushing and flowering took place during the wetter months (September to December), whereas fruiting took place all year. Phenologies differed between life-forms and were strongly associated with day length or temperature in the preceding months, implying that plants receive phenological cues well in advance of their phenological response. Phenologies tend to be associated with the most predictable and highly correlated climatic factors, daylength and temperature, and least so with the unpredictable rainfall in this Araucaria forest.

Ganesh and Davidar (2005) conducted long-term phenological studies in the mid-elevation non-dipterocarp wet forests of the southern Western Ghats, India, to investigate the impact of biotic and abiotic influences on phenological trends. The phenology of 42 tree species and the seed predation intensity of 35 tree species were studied. Nine of these species produced fruit every year, seven produced fruit every two years, and the remaining species produced fruit once in many years. The forest's main seed predators were two primates and two arboreal squirrels. Squirrels were obligate seed predators, while primates were responsible for some intact seed dispersal. Crop predators were the only seed dispersers for several tree species. Except for the lion-tailed macaque, which seemed to have seasonal population movement, seed predator abundance did not change substantially over time. In the forest, there was no evidence of a community-wide mass fruiting phenomenon, but there was considerable variance in fruit availability between years. Sometimes, a few tree species tended to display mast fruiting. Seed predation was a big problem for the majority of the species. For some species, seed predation intensity decreased during mast fruiting events, while for others, it had no impact. Predation severity did not vary between species that fruit annually and those that fruit supra-annually. Masting was restricted to a few tree species in the Western Ghats as a way of overcoming high seed predation at the population level.

Kushwaha and Singh (2005) studied the diversity of leaf phenology in a tropical deciduous forest in the Vindhyan region, India. Leaf phenological diversity patterns were observed in nine major tree species. Through two annual cycles, monthly leaf counts on 160 tagged twigs of ten individuals of each species were performed. The deciduousness of tree species ranged from semi-evergreen (the entire population never becomes leafless) to 7-month deciduous. Around the spring equinox, the semi-evergreen species began leaf flush (bud break of vegetative bud). During the hot, dry summer, all deciduous tree species experienced synchronous leaf-flush initiation with low inter-annual variability.

Sundarapandian *et al* (2005) studied the reproductive and vegetative phenology of 42 tropical tree species at Kodayar in the Western Ghats of Tamil Nadu, India, over the course of two years. All showed significant variations in leaf flushing, leaf fall, flowering, and fruiting activity, which could be due in part to abiotic factors. The early dry period's peak activity of leaf fall and leaf emergence may be an attempt to maximise the first rainy season's potential for vegetative growth and reproduction. Leaf fall coincided with peak flowering activity, likely to attract pollinators. In order to use the available soil moisture for seed germination and seedling establishment, the activity of fruit ripening and fruit fall was at its maximum during the first rainy season. The trees' phenological behaviour is an adaptation to the abiotic and biotic environments in which they live.

Bendix *et al* (2006) conducted a four-year study on the reproductive phenology of 12 tree species in a tropical evergreen mountain rain forest located in southern Ecuador. Phenological recordings and meteorological parameters were closely monitored and connected to the flowering and fruiting behaviour of the trees in their research. The results of this analysis revealed that the phenological behaviour of the trees studied typically follows an annual oscillation correlated with less and more humid periods. However, the degree to which most of the studied species produced flowers and fruits wss clearly influenced by seemingly irregular events, which are most likely caused by lower frequency oscillations. As a result of the research, Ecuador, which has the highest rate of deforestation in South America, needs native plant material for reforestation.

Elliott *et al* (2006) investigated the leafing behaviour of trees in Asian monsoon forests during the dry season. They discovered the proximate causes of monsoon forest trees characteristic and counter-intuitive ‘spring-flushing’. Trees of 20 different species were found in semi-deciduous dry monsoon forests in northern Thailand, where the dry season lasts 5-6 months and the annual rainfall is 800-1500 mm. They were found at 680-750 m altitude near Chiang Mai on dry ridges (dipterocarp–oak forest) or in moist gullies (mixed deciduous-evergreen forest), as well as in a dry lowland stand of *Shorea siamensis* in Uthai Thani province. Two new methods for analysing temporal and spatial variation in vegetative dry-season phenology indicative of differences in root access to subsoil water reserves have been developed. In January and February, evergreen species in cool, wet locations flush soon after partial leaf fall. Drought-hardy dipterocarp species were evergreen in moist areas but deciduous in dry areas, and trees flushed shortly after leaf fall if subsoil water was available. Leaf flushing of deciduous species around the spring equinox was common in Thailand's dipterocarp-oak forest and it seems to be common in the Indian dry monsoon forests of the Deccan plateau also, which have dark, water-storing soils. Leafing during the dry season in all observed species relied on subsoil water reserves, which protect trees from prolonged climatic drought. In other words, rainfall periodicity, or climate, is not the primary determinant of vegetative tree phenology. In dry monsoon forests with a relatively short, wet growing season, the establishment of new foliage before the summer rains is likely to optimise photosynthetic gain.

Lu *et al* (2006) investigated how the greenhouse effect alters phenological events in plants by causing changes in diurnal, annual, and inter-annual patterns. They found that the flowering times of four tree species, *Prunus armeniaca*, *P. davidina*, *Syringa oblata,* and *Robinia pseudoacacia,* were dramatically changed due to urban climate change in Beijing, China, from 1950 to 2004. Flowering in Beijing is most sensitive to the average temperature 30 days before the average blossom date, according to statistical analysis. The goodness of fit shows that spring-flowering dates can be predicted from the time when the temperature is above 0°C, based on the temperature response curve.

Mishra *et al* (2006) investigated the phenology of tree species in the moist deciduous forests of the Similipal biosphere reserve, Odisha, India. They examined the vegetative and reproductive phenology of 57 overstorey and 33 understorey species respectively. The peak period of phenological events such as leaf drop, leaf flush, and flowering differ slightly between understorey and overstorey species. Both overstorey and understorey species have the same peak fruiting period, which is from May to June. The flowering phenology is closely followed by the fruiting phenology. Fruit fall occurs before or just before the start of the monsoon season, ensuring that seeds have enough moisture for germination and seedling establishment. Changes in day length and temperature have triggered leaf drop, leaf flush, and flowering in both overstorey and understorey species, implying that soil moisture availability may have shaped the phenological patterns of both overstorey and understorey species. The phenological data collected in this study for both overstorey and understorey species is predominantly impacted by the seasons and might be utilised to establish appropriate management methods in the Similipal biosphere reserve to support promising regeneration.

Perglova *et al* (2006) investigated the flowering phenology of *Heracleum mantegazzianum*, an invasive species in the Czech Republic, and assessed the effect of protandry on inhibiting selfing in this self-compatible plant. They also discussed the timing of flowering in a densely invaded area and assessed fruit set in a large sample of plants. The degree of protandry in *H. mantegazzianum* favours outcrossing. However, for an invasive plant, the ability to self may be important, particularly if a single plant colonises a new area. The number of fruits produced by *H. Mantegazzianum* provides this invasive species with enormous reproductive potential, according to the report.

Selwyn and Parthasarathy (2006) analysed the reproductive traits of 84 plant species from 41 families in a tropical dry evergreen forest on India's Coromandel Coast. The reproductive phenophase of trees and lianas occurred primarily between January and June when rainfall was less than 50 mm per month. Shrubs, on the other hand, reported a peak in flowering and fruiting during the rainy season. Flowering was found to be seasonal and unimodal in 22 woody species after detailed phenological observations. While some species bloomed all year, flowering activity was overwhelmingly concentrated during the dry season. Fruiting activity was bimodal, with one peak in the dry season and another in the wet season. In flowering and fruiting, several species showed a temporal aggregation. In the tropical dry evergreen forest, a strong relationship was discovered between reproductive traits and the phenology of plants.

Using phenological data series for the cherry tree (*Prunus jamasakura*) deduced from old diaries and chronicles, Aono and Kazui (2008) reconstructed changes in springtime temperature in Kyoto, Japan, since the 9th century. By integrating data from past observations, phenological data for the last 732 years was made available. During February and March, the full flowering date of cherry trees varies depending on temperature conditions.

By using a temperature accumulation index, which considers plant growth to be an exponential function of temperature, full flowering dates were closely linked to the March mean temperature.

Bentos *et al* (2008) studied the reproductive phenology of important pioneer tree species in the successional forests of the Central Amazon. They selected 13 species and recorded their flowering and fruiting behaviour. Flowering occurred during the transition from the dry to the rainy season, while fruiting occurred during the rainy season. Tree pollinator type or dispersal mode had no effect on reproductive phenology. Year after year, the phenology of reproduction remained surprisingly constant. The phenological behaviours of the pioneer community varied, but they were all marked by annual flowering and fruiting, either continuously or seasonally, allowing generalisations of pioneer species relative to mature forest species.

Fonseca *et al* (2008) investigated the reproductive phenology of *Melocactus* (Cactaceae) species from Chapada Diamantina, Bahia, Brazil. The findings of the study suggested that these taxa share pollinators, phenological evidence contradicts this and supports the hypothesis of hybridization in the study region. In *M. paucispinus*, rainfall was negatively correlated with flowering but positively correlated with fruiting. Flowering in *M. paucispinus* during dry periods of the year protects the erect flowers in the terminal cephalium from rain damage, while fruiting during rainy periods helps the dispersion and germination of this species.

Geninia *et al* (2009) investigated the variety of fruits eaten by vertebrate frugivores on Anchieta Island, a Brazilian Atlantic rainforest island. Palm trees are an integral part of the neotropical rainforests and are a major food source for a variety of frugivores. As a result, in highly impoverished areas, their function as a keystone resource may be amplified. Human settlements have altered and degraded the forest, largely through overharvesting and the introduction of exotic plants and a number of mammals. The study compared whether palms and trees have different fruiting patterns and fruit fall, as well as the value of palms as a food source for frugivores, and the implications for Anchieta Island conservation. Both trees and palms had seasonal phenological patterns, but the periods of fruiting were different. Palms accounted for more than 80% of the total fruit fall biomass. While they do not provide resources for the entire assemblage of vertebrate frugivores, palms may provide an alternative food source during periods of low fruit availability. Fruits produced by palm trees are energy-rich fruits, which can play an important role in maintaining the vertebrate frugivore populations in isolated and disturbed ecosystems where the diversity of fruiting species and fruit biomass are significantly lower, such as on Anchieta Island. Anchieta Island is not the only location on the planet with highly disturbed natural conditions and large numbers of exotic species. The anthropogenic influences mentioned on Anchieta Island affect many sites, especially islands. In that sense, a primary effort in the conservation biology of such sites should be the identification and preservation of key resources such as palms, which can support other species and interactions.

Cosmulescu *et al* (2010) examined phenological changes in *Prunus domestica* trees grown in the Oltenia region of Romania. It was discovered that vegetative phenological phases formed much earlier in years with an early spring season and high temperatures. The results of the analysis revealed that 'flowering time duration' is a trait that is affected by both climatic and genetic factors. In general, the sooner flowering starts, the shorter the time it takes to complete. Studies on the effect of environmental factors on phenology in fruit tree species allow for the development of appropriate assortments for various culture zones, based on local ecological conditions.

Jadeja and Nakar (2010) conducted phenological studies on ten tree timber species from eight different families in Girnar reserve forest, Gujarat, India. The phenological behaviour of all the ten species was almost similar throughout the whole year. In majority of the species, leaves fall observed during the month of January, and new leaves began to emerge before the monsoon in February and March. Fruiting activity was at its peak in December for five species. In most species, the duration of leaf maturation was the lowest, but the duration of fruit ripening was the longest. Fruit dehiscence was completed in two species before pre-monsoon showers in June; the remaining eight species were indehiscent.

Sarma *et al* (2010) studied the gregarious flowering behaviour of *Bambusa tulda, Bambusa arundinacea*, and *Melocanna baccifera* in the Bajali lowland forest located in the Indo-Burma hotspot region from March to June 2008. Seeds of two kinds, bacca and caryopsis, were found in different species. Few bacca seeds produced by *M. baccifera* showed viviparous germination, which is an uncommon occurrence in bamboo. A seed viability test revealed that 75% of caryopsis seeds were viable, indicating they could germinate and be used for mass regeneration.

Sellamuthu and Lalitha (2010) studied the diversity and phenological characteristics of trees in the Kukkal Forest, Palni Hills, Tamil Nadu, India. There were 2279 individuals in total, divided into 83 species, 68 genera, and 40 families. Around 30% of the species were endemic to the Western Ghats, accounting for 12% of the total number of individuals sampled. Lauraceae was the most common family, accounting for 20% of the total number of individuals. Fruiting was at its highest in July 2003, and at its lowest in June 2002. Fruits from 85 individuals of six species were observed during the peak time. During the two years of research, *Syzygium tamilnadensis*, *Ilex wightiana*, and *Beilschmiedia wightii* produced fruits only once. Rainfall had no effect on the number of fruiting species, but there was a connection between fruit abundance and rainfall. The findings indicated that the montane wet temperate forest is exceptional in terms of diversity and phenology display.

Athokpam *et al* (2012) studied the leaf phenology of some important forest trees in Barak valley, southern Assam. Results of the leaf phenological studies in four evergreen and deciduous species of the valley showed that deciduous species may or may not begin their growth earlier than evergreen species, but deciduous species continue to produce leaves in tandem with soil moisture availability, long after evergreen species have stopped producing new leaves. Deciduous species lose all of their leaves before dry winters, which may help them conserve and store water and survive the cold, dry winters. Evergreen species, on the other hand, have an advantage over deciduous species because they can maintain growth during the dry winter season, and this longer photosynthetic activity allows evergreen species to achieve higher growth and dominance.

Bajpai *et al* (2012) studied the phenology of two tree species, *Shorea robusta* and *Ficus hispida*, in the Katerniaghat Wildlife Sanctuary, located in Uttar Pradesh, India. Different phenophases such as leaf bud initiation, young leaf formation, flower bud development, fruit formation, and leaf fall initiation were recorded on a monthly basis in the quantitative phenological study. Leaf bud busting and flowering/figging begin in both species in the post-winter months (March to April), with the most leaf fall occurring in the post-monsoon season (November to February). *Shorea robusta* fruiting began in the dry season (May) and continues until the monsoon season (June).

Nunes *et al* (2012) observed that various tropical dry forest tree species had different reproductive and vegetative phenological trends. The wet season saw the most flowering and fruiting, while the dry season saw the most leaf fall. Nonetheless, fruiting seemed to be linked to the various species' dispersal guilds. Temperature and precipitation were found to be linked to all of the phenophases tested, with the vegetative phenology showing the strongest associations. Species from the same area had more similar phenological trends than species from different locations. Adaptations that result in similar phenological trends among different species can be influenced by climate and soil conditions. Despite strong biotic interactions with processes including pollination, propagule dispersal, predation, and herbivory, environmental factors that directly affect phenological behaviour in tropical dry forest species often affect these biotic agents and decide the frequency of both vegetative and reproductive phenological patterns.

Padmavathi *et al* (2012) studied the phenological behaviour and reproductive biology of *Rhynchosia beddomei*, an ethnobotanically important medicinal plant endemic to the

Tirumala hills in Andhra Pradesh, India, and discovered that peak flowering happened in the last week of December, with a minor peak in early February. Pollen germination has been observed in the laboratory. Outcrossing was found to be more common than inbreeding, and it was caused by insects, especially bees.

Athokpam *et al* (2013) studied the variation in evergreen and deciduous species leaf phenology in Assam for three years. From March 2007 to March 2010, they documented the phenological observations such as leaf and shoot growth, leaf size, and leaf shedding in 19 tree species including 13 evergreen and 6 deciduous in a moist tropical forest. The study area receives a total annual average rainfall of 2,318 mm, with the majority of rain falling (>70%) between June and September. On the majority of shoot and leaf phenology parameters, both plant groups differed significantly. In general, growth in deciduous species began before growth in evergreen species, and deciduous species showed faster shoot growth, leaf recruitment, and leaf expansion than evergreen species. The leaf recruitment period differed significantly between evergreen (4.2 months) and deciduous species (6.8 months). The rate of shoot elongation differed significantly between evergreen and deciduous species (0.09 vs. 0.14 cm day1 shoot1). The number of leaves per shoot was greater in deciduous species than in evergreen species (34 vs. 16 leaves). Evergreen species had a substantially longer average leaf life span (328±32 days) than deciduous species (205±16 days. Leaf fall was concentrated in deciduous species during the winter season (Nov-Feb), whereas evergreens retained their leaves until the following growing season. Although the climate favours evergreen forests, deciduous species' rapid leaf recruitment rate, lengthier leaf recruitment period, and faster shoot elongation rate during the growing season, and short life span of leaves enable them to coexist with evergreen species that can perform photosynthesis throughout the year. Variations in phenological strategies may help to reduce competition for resources among evergreen and deciduous species in these forests, allowing both groups to coexist.

Kaur *et al* (2013) studied the phenology of some phanerogams (trees and shrubs) of northwestern Punjab, India. For three years, from 2009 to 2011, phenological activities such as bud formation, flowering time, fruiting time, and seed formation were studied for some leguminous plants in Amritsar, Punjab (India). The study revealed that fifteen leguminous plant species growing in Amritsar with tropical dry deciduous vegetation have a good amount of phenological diversity for four different phenophases. It would be extremely beneficial to know the timing of various phenophases of the studied plants, which may be of interest to people in this region (or elsewhere with similar climatic conditions) who want to plan their gardens and have flowers all year. As a result, they can choose plants that bloom at different times of the year. This type of research can reveal phenological patterns of surveyed species and provide important insights into the biology of the plants involved. It would also be extremely useful for making long-term comparisons.

Kumar and Kalavathy (2013) evaluated the impact of human activities on the phenological cycle of important tree species in the dry deciduous forest of the North Gujarat region, India for two years. From January 2006 to December 2007, phenological observations were made on 13 woody species. The phenological behaviour of most woody species was nearly identical in two different years. Leaf initiation began in March, with a peak in April-May before pre-monsoon showers, and leaf fall began in October, with a peak in November and December. Flowering was observed in most woody species in February and continued until May, with fruit appearance beginning in March and peaking in August. In July and August, 69 per cent of woody species had fruit ripening. While the monsoon begins at the same time each year, this allows for optimal germination of tree species. Observing the human impact on selected species facing seasonal threats, it was noticed that a greater number of species were cut during the leaf fall period or before flowering.

Borah and Devi (2014) investigated the key phenophases such as seedling survival and growth of *Vatica lanceaefolia*, a critically endangered species threatened by habitat loss, in two separate regions of the Hollongapar Gibbon Wildlife Sanctuary in Assam. The study was conducted over 24 months to investigate various phenophases in relation to seasonal variations of the year and to understand the growth and survival of seedlings in two micro sites (gap and understory) in relation to the study area's prevailing meteorological parameters. Leaf initiation was observed in December and May, whereas flowering and fruiting were recorded during the pre-monsoon months, i.e. April and May. The seedlings survived better in the gap (66.6%) than in the understory (46.6%). Relative growth rates with respect to height and collar diameter differed considerably between the months as well as between the two different sites. The wet monsoon season aided seedling survival and growth. The study area's relative humidity (P0.05), average temperature (P0.05), and rainfall (P0.05) all had a positive correlation with the growth of *V. lanceaefolia* seedlings in both micro sites.

Kumar *et al* (2014) studied the phenological characteristics of different forest trees in south Gujarat and observed a variety of reproductive and survival strategies evolved under the monsoonal bio-climate in India. The drought stress was not only reflected in terms of the leafless period, but is also evident from the greater seasonal separation between leafing and flowering. Flowering time and the time lag between the onset of leafing and flowering affect the degree of separation of resource use for vegetative and reproductive events within tree species. Flowering periodicity has evolved in tropical deciduous tree species as an adaptation to the annual leafless period, which affects the rate and duration of vegetative growth, and the time necessary for fruit formation. The predominance of summer flowering in association with summer leaf flushing seems to be a unique adaptation to survive in a seasonal climate. Because environmental factors influence reproductive phenology through habitat conditions or indirectly through the leafless period, global climatic change is likely to have severe ramifications for the future reproductive success of trees in dry-tropical forests.

Nakar *et al* (2014) carried out phenological studies of two Bombacaceaen members from Girnar reserve forest, Junagadh, Gujarat, India on two different tree woody species, viz. *Adansonia digitata* L. and *Bombax ceiba* L. of the Bombacaceae family during the year 2008-10. The phenological behaviours of both species were a little different throughout the period of observation. In *Adansonia digitata* L., new foliage and leaf fall lasted 50 and 131.5 days, respectively, as the mean value for both years, while flowering and fruiting lasted 50.5 and 33 days, respectively. New foliage and leaf fall were observed in *Bombax ceiba* L. during 48.5 and 138.5 mean days, respectively, while flowering and fruiting lasted 51 and 58.5 days, respectively. The period of fresh foliage to leaf fall in *Adansonia digitata* L was roughly 196 days, but in *Bombax ceiba* L it was more than 330 days, according to inter phenophase phenology. The study also looked at phenological characteristics such as stem diameter, number of branches per tree, number of leaves per branch, number of inflorescences per branch, number of flowers per branch, and number of fruits per branch.

Nanda *et al* (2014) described the vegetative and reproductive phenology of canopy trees in the dry deciduous forest of Bhadra wildlife sanctuary in Karnataka, India for two years. From June 2004 to May 2006, all of the woody canopy individuals having more than 20 cm girth at breast height were identified and tagged with a unique number along a 2-kilometre transect that included 157 individuals from 22 different species. From June 2004 to May 2006, leafing, flowering, and fruiting phenophases were observed at monthly intervals. It has been discovered that leaf fall began in September and peaked in December and January. Leaf initiation began in February and peaked in April, just before the monsoon season. Leaf expansion began in February before the monsoon and peaked in May and July during the monsoon. Leaf senescence began in September and continued through November, peaked in January and March. Flower bud formation began in January, with a peak in April and May, and pollination began in April, with a peak in May and July prior to the monsoon's arrival. Fruit bud formation began in May and peaked in September and October. Unripe fruit was first noticed in May, with a peak in September and November. Fruit harvesting began in November and peaked in March. Their findings indicated that leafing and flowering activities occur during the summer or pre-monsoon season. Different fruiting patterns were observed during the monsoon and post-monsoon seasons. Seasonality among various phenophases showed that leaf senescence, flower initiation, and fruit fall are highly seasonal.

Pandey *et al* (2014) investigated the leaf characteristics such as leaf area, leaf water content, leaf fresh weight, leaf dry weight, specific leaf area, and chlorophyll content of eight woody species, namely, *Buchanania lanzan, Lagerstroemia parviflora, Shorea robusta, Lannea coromandelica*, *Lantana camara*, *Terminalia tomentosa*, *Holarrhena antidysenterica*, and *Diospyros melanoxylon.* Observations were taken from four sites in a dry tropical deciduous forest during the 2008-2010 period. Leaf traits varied significantly across species, months, and sites. Leaf traits, on the other hand, showed less variation between sites than between species. The leaf lifespan ranged from 7 to 12 months (*L. coromandelica*) (*S. robusta*). Species differed in the length of their deciduous period on the same sites. Maximum leaf area, leaf dry weight, leaf fresh weight, and leaf water content were recorded for semi-evergreen species, specific leaf area for long-deciduous species, and chlorophyll content for short-deciduous species. The coefficient of variation for leaf dry weight was the highest and the lowest for chlorophyll content. Among the eight woody species, *T. tomentosa* exhibited the greatest leaf area, leaf dry weight, leaf fresh weight and leaf water content.

Bajpai *et al* (2015) investigated the periodicity of distinct phenophases in selected trees from India's Himalayan Terai. From November 2009 to October 2012, phenological observations such as leaf initiation, leaf development, leaf drop, flower initiation, fruit maturation, and fruit drop were recorded for the tree species *Pongamia pinnata*, *Shorea robusta, Ficus hispida*, *Ficus squamosa*, *Terminalia arjuna*, *Mallotus nudiflorus*, *Mallotus philippensis*, and *Schleichera oleosa.* Summer leaf flushing was triggered by a short low-temperature dry period, sufficient winter rain, and temperature rise, according to the study, as well as increased soil water availability for second leaf flushing after rain. Flowering began with leaf emergence in the dry season, which promoted a higher rate of fruit set due to increased pollinator availability and activity. Fruits that ripened before and/or during the rainy season had better dispersal and post-dispersal success. There is no correlation between fruiting and rain in *T. arjuna*. *M. nudiflorus* and *M. philippensis* begin to produce leaves and flowers with the first considerable increase in temperature and photoperiod, and are thus suggested as ideal tree species for climate change studies in the tropics. Fruit setting begins in the dry months and is aided by high temperatures, which allow the fruits to mature quickly. Fruits that have been allowed to ripen before the rain have a better chance of germinating. *T. arjuna* produced and matured its fruits until the late rains, when they were able to withstand the winter rains.

Echereme *et al* (2015) carried out an annual cycle phenological study of *Azadirachta indica* growing in Onitsha, Nigeria in tropical deciduous vegetation to record and document the phenological activities of the species. Bud break, i.e., both vegetative and reproductive, leaf flushing, inflorescence emergence, fruit development, and fruit ripening were recorded. As an outcome of the research, the tree displayed two sub-annual cycles in both vegetative and reproductive functions, which were reported during the rainy and summer seasons. In the sub-annual cycles, there was no time lag between the onset of leaf flushing and the emergence of inflorescence in *A. indica*. In the drought-stricken dry season, the onset of leafing and flowering in the species increased the rate of leaf fall and extended the duration of deciduousness more than in the wet season. Also, during the drought-stricken dry season, there was an advance in fruit ripening. As a result, long-term phenological observation and documentation of the species were recommended for future reference, particularly in tracing the impact of climate change on the plant.

Singh *et al* (2019) studied the vegetative and reproductive phenological behaviours of six prominent tree species in the natural forest situated inside the Mizoram University Campus, Aizawal, India. The phenological variations in the selected deciduous and evergreen tree species were striking. Evergreen trees shed old leaves all year and flush new leaves several times, with a peak period near the end of the dry season. However, deciduous trees flush new shoots after rain during the wet season. Except for *Schima wallichii*, which has new shoots emerge simultaneously during flowering, evergreen species flower mostly after leaf flushing, whereas deciduous species flower soon after leaf flushing. Except for *Callicarpa arborea*, which had a brief and rapid fruit maturation period, the majority of the species had a lengthy fruit maturation period that lasted up to five months. When compared to the phenological status recorded in the flora of the Lushai Hills in 1938, the flowering and fruiting times of the selected species were either advanced or delayed. As a result, observations of tree phenology in response to climate change are critical for forecasting future impacts. The phenological observations made in this study will be useful for both in-situ and ex-situ conservation of the tree species studied.

Venugopal *et al* (2020) investigated the vegetative and reproductive phenology of *Mesua ferrea* L., a rare medicinal tropical tree, in two different populations located in Kerala, India. Besides the phenological studies, the metabolical changes during seed development in two *M. ferrea* populations were also studied. Though there was a slight difference in leaf and flower flushing between the two populations, there was no significant difference in fruit/seed development. Pollinating agents have been identified as well. Seed development began after pollination, with an increase in seed moisture content, fresh seed, and dry weight. 60 days after anthesis, the moisture content began to decline and by 160 DAA, it had dropped to 44.58 per cent. The amount of total sugar, starch, protein, and lipids in the seed increased during seed development, and its role has been discussed.

2.1.2 Phenology and Climate Change

Karmer (1997) studied the phenological behaviour and growth characteristics of European trees in the context of climate change. He gave an overview of phenological models that can be used for boreal, temperate deciduous, and Mediterranean forest biomes. The phenology of boreal forests is primarily influenced by temperature, which influences the timing of the growing season and thus its duration, as well as the level of frost hardiness, which influences the reduction of foliage area and photosynthetic capacity caused by severe frost events. Temperature also has a strong influence on the phenology of temperate-zone forests. Because temperate-zone forests are mostly mixed-species deciduous forests, differences in phenological response may affect tree species competition. The phenology of Mediterranean coniferous forests is primarily determined by water availability, which influences leaf area development rather than the timing of phenological events. These phenological models were then combined with a process-oriented forest model, FORGRO, to analyse the effects of various climate change events on growth. The findings showed that the phenology of each forest type has a significant impact on the growth response to a given climate change scenario. However, given there were still ambiguities in the phenological and growth models, values derived, and climate change models employed in this study, the absolute responses reported in this work should be taken with caution. It was suggested that phenological models be prepared and thoroughly tested to explain the processes by which seasonal changes in climatic drivers influence the phenological features of trees. Only by employing such models can we assess the impact of climate change on the functioning and productivity of various forest ecosystems.

Borchert *et al* (1998) studied the response of tropical trees to rainfall seasonality and its long-term changes. The seasonality and physiognomy of tropical forests were primarily determined by the amount of annual rainfall and its seasonal distribution, according to this study. Climate change scenarios predict that global warming will result in lower annual rainfall and longer dry seasons for some tropical rainforests, but not all. Tropical trees can mitigate the effects of seasonal drought through adaptive mechanisms such as leaf shedding or stem succulence, as well as by utilising soil water reserves, which helps to maintain an evergreen canopy during instances of little rainfall. The correlations between climate and tropical tree responses are thus poor, and the responses of tropical rainforests to climatic changes are difficult to predict. Climate change is unlikely to have an impact on the physiology of rainforests with high annual rainfall and low seasonality. Once rainfall becomes insufficient to replenish soil water reserves regularly, seasonal evergreen forests that rely on soil water reserves will be replaced by more drought-tolerant semi-deciduous forests. Because the limits of tropical rainforest drought tolerance are unknown, the rate and magnitude of future changes cannot be predicted.

According to Cubasch *et al* (2001), cloud cover and atmospheric vapour pressure deficit are extremely important. Deforestation in the tropics can reduce cloud cover and evapotranspiration. This has the potential to alter atmospheric conditions in tropical regions. They opined that phenology may be less susceptible to temperature and photoperiod in tropical environments, and more tuned to seasonal changes in precipitation, which are expected to take place in tandem with increasing global temperatures. Regionally, however, both the direction and degree of change differ.

Borchert *et al* (2002) investigated how unusual drought and rain altered vegetative phenology in a tropical semi-deciduous forest. Leaf abscission in dry forest trees can be sped up by increased leaf age, high water stress, or reduced photoperiod. It is normally impossible to assess the effects of each of these variables because most of the leaves are lost during the early dry season, when day length is at its shortest and the leaves are relatively old. The El-Nino Southern Oscillation created a two-month long, severe atypical drought in Guanacaste, Costa Rica's semi-deciduous forests, from June to August 1997. They observed the effect of the drought on the phenology and water status of trees with young leaves and compared phenology modifications in trees of different functional types to the pattern observed during the regular dry season. Even though deciduous trees in dry areas were extremely water-stressed and their mesic leaves continued to wilt for more than two months, these and all other trees maintained all of their foliage during the unprecedented drought. During the wet period following the abnormal drought, many trees shed leaves three to four months earlier than usual and then shed leaves again during the regular dry season. Irrigation and an extraordinary rainfall of 70 mm during the 1998-1999 dry season caused bud break and flushing in almost all leafless trees but dormant stem succulents. The complex interactions between leaf age and water stress, which are the primary determinants of leaf abscission, were discovered to vary greatly among trees of different functional types.

Chapman *et al.* (2005) conducted a long-term evaluation of fruiting phenology to find out its relationship with climate change. They described the fruiting patterns of the tropical tree community in Kibale National Park, Uganda, using two data sets (1970-1983 and 1990-2002). They described fruiting over 2-3 years at four sites separated by 12-15 km to address variation in spatial patterns. The Kibale region now receives 300 mm or more rainfall than it did at the turn of the century, droughts are less common, the rainy season begins earlier, and the average maximum monthly temperature is 3.5°C higher than it was 25 years ago. The phenology data from 1990 to 2002 revealed high temporal variability in the proportion of populations fruiting. Interannual variations in fruit production were also considerable throughout the community. Nevertheless, the proportion of fruiting trees has increased over the last 12 years. A variety of patterns were observed at the species level. However, many of the most common species now infrequently fruit, and when they do, only around four per cent of the individuals participate in fruiting events. Combining data sets from 1970 to 1983 with those from 1990 to 2002 for individual species indicates an increase in the number of trees fruiting between 1990 and 2002, but a drop in the proportion of populations fruiting prior to 1990. When specific species are examined over this period, a variety of patterns emerge. *Pouteria altissima*, for example, had a fairly regular fruiting pattern in the 1970s but infrequently fruited in the 1990s. When changes in fruiting patterns over 30 years are compared to differences in rainfall between the four sites, it appears that the fruiting changes observed may be linked to climate change. The relationships between rainfall and fruiting varied by site. When changes in fruiting behaviour over 30 years are compared to differences in rainfall between the four sites, it appears that the fruiting changes observed may be linked to climate change. Climate change responses are likely to be complex and species-specific.

Chuine *et al* (2007) found that, on average, leaf unfolding in major forest trees has advanced at a rate of 2.9 days per decade since 1950 in temperate zone tree species. Leaf unfolding is an important ecosystem parameter that affects forest dynamics and controls carbon and water fluxes. Since this parameter is extremely sensitive to temperature, it is commonly used as a global warming indicator. According to Loustau *et al* (2007), leaf unfolding should advance at a rate of 5.4 to 10.8 days per decade from 2000 to 2050 if phenological changes are linear with warming. Thus, by 2050, leaf unfolding in temperate regions could occur 27 to 54 days earlier than it does now. The mechanisms that regulate tropical tree phenology are largely unknown. Korner and Basler (2010) opined that certain opportunistic taxa can benefit from a warmer climate and therefore, gain a competitive advantage over photoperiod-sensitive taxa as a result of global warming.

Ibanez *et al* (2010) investigated the topic, forecasting phenology under global warming. According to the study, as a result of global warming, spring and autumn phenologies have shifted, resulting in changes in the length of the growing season. Not all species respond in the same way, and even within species, there is significant spatial variation in responses. This spatial and interspecific variation complicates efforts to predict phenological responses to ongoing climate change, but it was necessary to account for it in order to develop reliable forecasts. They used a long-term dataset of plant phenological events during spring (flowering and leaf initiation) and autumn (leaf tint and leaf shedding) seasons from South Korea and Japan to create predictions that account for these sources of variability from 1953 to 2005. They employed hierarchical models to include geographical variability in phenological responses to temperature, allowing them to estimate species-wide and site-specific responses to global warming and climate change. It has been discovered that for most species, spring phenology advances while autumn phenology lags, with the timing of events shifting faster in autumn than in spring. East Asian temporal trends and phenological responses to temperature contrasted with results from comparable studies in Europe, where spring events change faster than autumn events. Their findings highlighted the importance of studying multiple species at multiple sites in order to understand and forecast regional phenology changes. According to Kallarackal and Roby (2012), observations in general indicate that leaf unfolding, flowering, fruit ripening, and leaf colouration will occur earlier in the next few decades than currently observed. The physiological basis for the influence of the environment on tree phenology is not well known, despite significant progress in modelling.

2.1.3 Phenological Studies in *Pongamia pinnata*

Dhillon *et al* (2009) studied the reproductive biology and breeding behaviour of karanj (*Pongamia pinnata*) in Hisar, Haryana, India. They noticed that the initiation of buds appeared along with new foliage during early April. Inflorescence was a raceme or panicle with 43-88 floral buds which took 13-16 days to bloom. Peak flowering was from 13 to 21 days and pod setting and development was maximum from June to August. Complete development and maturity took some 323-344 days. Honeybees, wasps and thrips were the major pollinators. Since there was no pod setting under selfing bags and open pollination was considerably low (9.6 to 40%), the species appears predominantly cross fertilizing.

Rout *et al* (2009) noticed that for breeding programmes to achieve superior traits, a comprehensive understanding of phenological activity at time of anthesis, time and length of stigma receptivity, fertilisation, type of pollination, and seed development is required. Quality seed collection is critical in this crop because this oilseed crop loses viability quickly and is defined by researchers as microbiotic. Seed maturity is an environmentally affected genetic factor that has a significant impact on seed quality. In this large tree, using time to collect ripened seeds is inconvenient and necessitates an alternative method of collecting good seeds.

Raut *et al* (2011) studied seed and fruit variability in *Pongamia pinnata* from Maharashtra's Konkan region. Pongam fruits and seeds were collected from 20 seed sources from various agro-climatic zones across the Konkan regions. The result showed that the length of the pods ranged from 14.40 mm to 69.65 mm, while the thickness of the pods varied greatly across all seed sources. The seed thickness ranged from 5.00 to 10.00 mm, and the oil content ranged from 31.23 to 43%. It was found that the variability in seed source properties is mostly due to genetic heterogeneity and genotype X environment interactions.

Srimathi *et al* (2013) studied reproductive phenology, fruit and seed development, and harvest index based on pod colour in *Pongamia pinnata* and discovered that the flowers per inflorescence ranged from 28.5 to 44.1, with only a maximum of 4 per cent of the flowers developing as pods. However, only 80 per cent of pods obtained seed sets. Pod maturation study showed that seeds acquired physiological maturity about 26 weeks following anthesis, which was characterized by a change in pod colour from green to dark brown and seed colour from greenish-white to dark brown. They discovered that light brown fruits have the highest germination capacity for seeds, which could also be used as a harvest index for the extraction of good quality seeds in pongam. Several experts see fruit colour as an indicator of seed development, particularly in forestry (Khullar *et al* 1991, Srimathi 1997). Willan (1985) also suggested that fruit colours might be used to collect high-quality seeds in forestry.

Kumar *et al* (2015) examined the reproductive phenology of *Pongamia pinnata* and discovered that flower buds began to form in mid-April and yield an average of 35 flowers per inflorescence. Only 3-4 per cent of the flowers developed into pods, with less than 80 per cent of pods setting seeds. Pongam fruits (pods) reach physiological maturity within 26 to 27 weeks following anthesis, and seed gathered at this stage has superior seed and seedling quality. When collecting seeds in mass, the colour of the pongam fruits (pods) ranges from green, light brown to dark brown.

2.2 Fruit yield estimation and development of prediction models

Gleason (1974) compared several different regression models to see which one was best for predicting average pecan yield per tree based on data collected in central and southern Mississippi in 1972. He proposed criteria for determining which variables and, ultimately, which regression models are superior. A simple linear regression model based on the number of nuts counted on was found to be ‘ideal’ using the proposed criteria. He also made recommendations for further research for more precise results.

Peters *et al* (1988) pioneered fruit-based allometry by developing allometric equations that linked stem diameter to fruit biomass of trees and shrubs on Barbados. There have been no significant studies on the fruit-based allometry of forest trees since then, most likely because the need to measure fruit biomass in the wild was not yet relevant. Branch diameter and fruit crop weight data from 22 Barbadian tree and shrub species were collected to develop regression models between plant size and fruit crop weight. Orchard plants produce considerably more fruits than equivalent-sized wild or garden plants, but this difference disappears when multiple regression of fruit crop weight (F in g, fresh weight) on branch or stem diameter (D in cm) and individual fruit weight (W in g) is performed: $F=22D^{1.2} W^{0.57}$ is performed. This explains 89 per cent of the variation in F and accurately forecasts fruit weight for wild tropical and temperate species of trees and shrubs, but it greatly underestimates fruit weight for commercial temperate fruit trees. Crop weight is a small load compared to branch weight for larger branches when comparing feral, wild, and garden plants (Ff) using a simple regression, Ff=47D1.9. While fruit crops make up a smaller proportion of total plant weight as plants grow larger, they grow larger in comparison to leaf and twig weight, indicating that larger plants have more reproductive investment. Eventually, their equations, when combined with the self-thinning law, indicate that stands of large species of fruit plants yield more fruit per unit of land area than stands of small ones.

Venable (1992) observed that numerous factors, including seed size, tree size, soil nutrient supply, and competition from neighbouring trees, might influence fruit yield at the individual tree level. Larger trees are able to produce more fruits after reaching maturity (Greene and Johnson 1994), probably because of better access to resources. Larger trees can absorb and store more nutrients and carbohydrates (Carbone *et al* 2013), and they yield more fruits. In general tree diameter has a relation with fruit yield in all species except palm species where height is considered as an important factor as they grow in height, while very little increase in diameter (De Steven *et al* 1987).

Lamien *et al* (2007) developed fruit yield prediction models for *Vitellaria paradoxa* based on dendrometric and fruiting variables to investigate differences in these variables between upland and lowland populations in Burkina Faso. A total of 191 fruiting trees were selected based on crown accessibility, and 17 dendrometric and fruiting attributes were recorded. Fruit yield was calculated by gathering fruits dropped overnight until the end of the fruiting period, which was expressed in number of fruits per tree, as well as the fresh and dry weights of fruits. For each population, partial least squares regression was used to develop fruit yield prediction models. Dendrometric and fruiting variables between populations differed significantly ($P < 0.01$). The lowland population had the highest values for most dendrometric variables, while the upland population had the highest values for fruiting variables. The number of shoots and the fruiting variables had a strong significant correlation ($P < 0.01$). Fruit yield was lowest in the bottom part of the crown and the northeast portion of the crown within individual trees. Fruit yield parameters were accurately predicted using dendrometric and fruiting factors in which prediction error is found to be 0.092 and 0.125,respectively, for highland and lowland populations. The models were most influenced by all fruiting variables, the number of shoots, and crown characteristics.

Nyoka *et al* (2015) investigated the difference in growth and fruit output of populations of *Sclerocarya birrea* A. Rich (marula), one of the most famous indigenously grown fruit tree species in southern Africa, where it plays a vital part in the native people's diet, tradition, and culture. Over the last decade, the species has been subjected to domestication in order to expand its cultivation on a larger scale, as well as conservation in order to conserve its genetic variety. Nyoka and colleagues reported the performance of 21 geographic populations of *S. birrea* planted in Mangochi, Malawi. After 7 years out-planting, the trial was evaluated for tree height, bole height, root collar diameter, diameter at breast height, crown width and fruiting. For the majority of the attributes, there were significant disparities between the populations. The differences between the highest and lowest ranked populations were frequently up to threefold, indicating a high level of genetic diversity in the germplasm. The Mozambican Marracuene population rated first in terms of height, root collar diameter, DBH, crown width, and crown width. Only eight populations produced fruits, with the Marracuene population producing the most. Despite the fact that the average fruit load per tree varied from one to 274 amongst these fruiting populations, tree-to-tree diversity in crop yield ranged from one to 1,228 fruits per tree. The phenotypic correlations between growth and crown size variables (height, RCD, DBH, and crown width) were all found to be significant (P 0.001). Correlations between fruit weight and growth and crown size features were usually moderate, despite being significant and positive. The implications of this large genetic heterogeneity in growth and fruit yield observed among marula populations are examined in terms of conservation, breeding, and seed source selection for planting.

Brym and Zachary (2016) investigated allometric relationships in length, diameter, and mass of branches for two orchard tree species, tart cherry and apple, with differing management practices. The relationship between trunk diameter and stem biomass was the most consistent. Allometric relationships define the relationship between plant size (e.g., mass or diameter) and other morphological measurements including branch length, surface area, or volume. Power law equations of the form y = y0xa are commonly used to describe these relationships where y is the measurement of some trait of interest, x is a measure of plant size, and y0 and a are fitted parameters.

According to Minor and Kobe (2018), direct impacts on fruit yield were mediated by tree size and competition from neighbouring trees rather than soil nutrients. They studied fruit production in a moist tropical forest in Costa Rica for three years, observing 2,000 trees of 17 different species. Fruit yield was predicted as a function of tree size, nutrient supply, and competition in the neighbourhood. Following model selection, tree size and neighbourhood competition predicted the possibility of reproduction as well as the number of fruits produced.

Akweni *et al* (2020) developed fruit-based allometric equations for *Strychnos madagascariensis* and *strychnos spinosa* species. During the fruit ripening season, a total of 80 trees were chosen using a stratified sampling method based on four stem diameter classes. The fruit biomass, diameter at breast height (DBH), canopy diameter, and total height of each tree were all measured. Using the ordinary least squares method, six types of allometric models were fitted to the data. The best models were selected using the Akaike information criterion, and the accuracy of the predictions was assessed using the Root Mean Squared Error (RMSE). DBH was the only variable that could be used to predict fruit biomass, and it described 99.9% of the variation. The best models for *Strychnos madagascariensis* and *Strychnos spinosa* were simple linear regressions linking DBH (in cm) to total fresh fruit biomass (FB; in kg), expressed as; $\mathrm{FB} = 1.0243 \times DBH^{1.1841}$; and $\mathrm{FB} = 1.0297 \times DBH^{1.1956}$ respectively. These formulas provided accurate estimates of fresh fruit biomass. On average, they caused a 5.4 kg prediction error in a tree's total fresh fruit biomass. Fruit biomass prediction errors were more common in larger trees than in smaller trees. From the findings of their study, they concluded that estimation of fresh fruit biomass of trees in savannah woodlands is best done using simple linear regression based on DBH.

CHAPTER III

MATERIALS AND METHODS

The study entitled "Phenological behaviour and development of fruit yield prediction models in *Pongamia pinnata* (L.) Pierre under Punjab conditions" was carried out in the Punjab Agricultural University, Ludhiana. It consisted of two experiments.

1. Study of phenological behaviour in *Pongamia pinnata* under Punjab conditions.
2. Estimation of fruit yield in *Pongamia pinnata* under Punjab conditions.

3.1 EXPERIMENT NO. 1

Name of Experiment: Study of phenological behaviour in *Pongamia pinnata* under Punjab conditions.

3.1.1 Experimental Site

3.1.1.1 Location

The experimental location is situated in the main campus of Punjab Agricultural University, Ludhiana district of Punjab covers an area of 6.1 km^2 which is situated at 30.9010° N latitude and 75.8071° E longitude and an altitude of 262 MSL having sufficient plants of *Pongamia pinnata.*

3.1.1.2 Climate

Punjab is a state located in the north-western region of India, known as the 'food basket of India'. The climate in Punjab is characterised by scorching summer and extremely cold winter conditions. The territory near the Himalayan foothills receives good amount of rainfall, but the region farther away from the slopes is scanty of rainfall and experiences hot climate.

The climate of Punjab is divided into three distinct seasons. The summer season starts during April and severe hot conditions prevails till the end of June. Monsoon reaches Punjab during early July and ends in September. Punjab's winter season spans between early December and late February. The post-monsoon and the post-winter are recognised as two transitional seasons in Punjab.

Summer in Punjab officially begins in mid-April. However, from February onwards, the temperature begins to rise. Between May and August, high temperatures range from 40 to 47 °C. During the summer, the area experiences variations in atmospheric pressure. In February, the air pressure in the region is approximately 986 millibar, with 971 millibar in June. The rainy seasons come after the summer months. The monsoon season brings the majority of the rain to the region. The monsoonal current that flows across the Bay of Bengal brings the monsoon to the state, and it arrives in the first week of July from the southeast. Rainfall varies between 250mm and 1000mm. The state's agriculture heavily depends on the amount of rainfall.

The winter season in Punjab reaches its coldest episode during the month of January when average night and day temperatures are 5 °C (41 °F) and 12 °C (54 °F), respectively. It is chilly, with temperatures plunging to below freezing in some areas. Western disturbances are also prevalent in winter which also brings in some rainfall. It is very important in the agriculture scenario, since winter crops cultivating on Shivalik hills are totally dependent on this rains. During the winter months, the Shivalik region gets more than 100 millimetres (3.9 in) of rainfall, according to meteorological data.

The post-monsoon transitional season is moderately dry and pleasant. Hail storms are also happen sometimes during the post-winter transitional season, causing crop loss. By the end of March, the weather becomes dry and summer season begins. The state's economy is heavily depends on its climate.

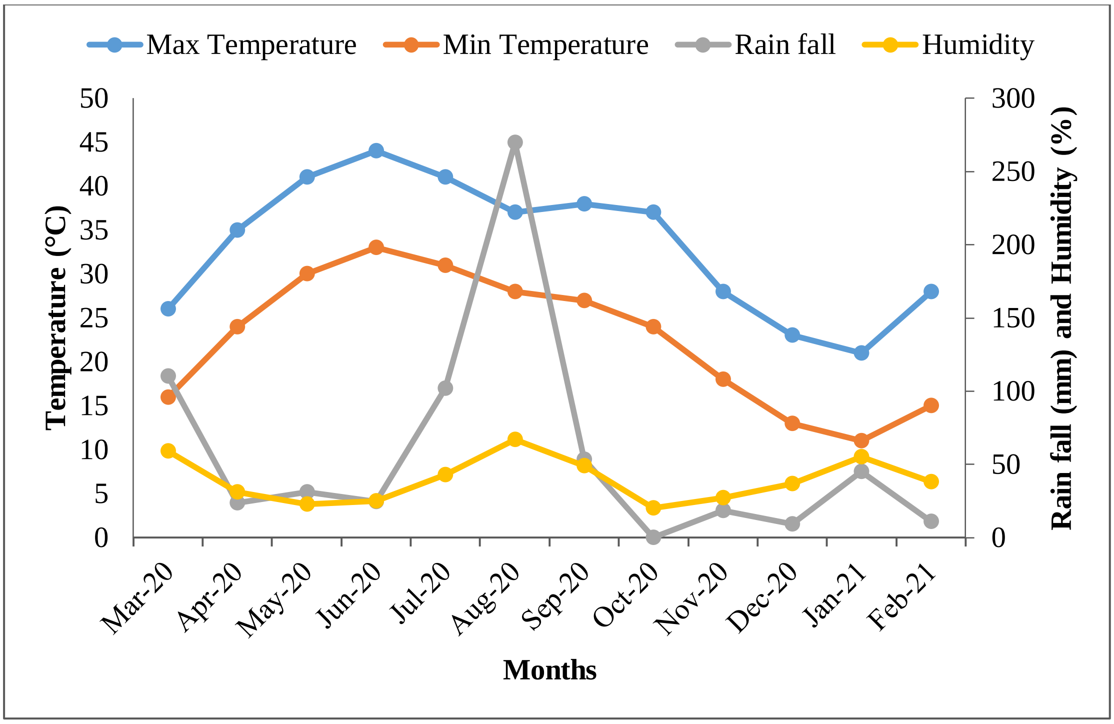

Fig. 3.1: **Climate of study site with maximum temperature, minimum temperature, rainfall and humidity**

3.1.2 Methodology

Morphologically healthy pongam trees were selected and marked by using simple random sampling inside the main campus of Punjab Agricultural University. Ten adult individuals (>30cm GBH and >6m height) were selected permanently. Four main branches (from four directions) were chosen from each selected tree, and four twigs from each branch were tagged. The year is divisible into three seasons: summer (April to June), monsoon (July to September) and winter (December to February). The selected trees were used for studying leaf initiation, completion, leaf fall, flower phenology, and pod development.

From the 160 twigs of ten trees, phenological data were obtained. The information was gathered in the middle of every month. The species was represented by the mean values of observed phenophases of all ten trees. All the meteorological data were obtained from an online source on a monthly basis (www.worldweatheronline.com).

3.1.3 Observations Recorded

Table of the following observations were recorded for various phenophases (in days) in *Pongamia pinnata* under Punjab conditions

- Leaf fall period (Initiation to completion)
- Leaf less period
- Leaf-flush period (Initiation to completion)
- Flowering period (Initiation to completion)
- Fruiting period (Initiation to fruit ripening)
- Change of colour of the fruit
- Fruit fall period (Initiation to completion)

3.2 EXPERIMENT NO. 2

Name of Experiment: Estimation of fruit yield in *Pongamia pinnata* under Punjab conditions.

3.2.1 Experimental Site

3.2.1.1 Location

The experimental location is situated along the roadside plantations, Hambran Road, Ludhiana district of Punjab covers a distance of 2.5 km and is situated at 30.9277° N latitude and 75.7475° E longitude at an altitude of 262 MSL having sufficient plants of *Pongamia pinnata.*

3.2.1.2 Climate

Since the road side plantations are near to PAU campus, different climatic features are same as that of experiment no.1

3.2.2 Methodology

Trees from different available diameter ranges (minimum 10 cm diameter) were selected for the estimation of fruit yield and other tree parameters. Fully ripened fruits were collected from the selected trees at the full maturity stage, i.e., when pods were brown in colour. Analysis of the data were done to prepare prediction models of fruit yield with respect to different DBH classes.

The trees were selected by simple random sampling technique based on their girth at breast height. The values were converted to DBH and the trees were divided into six classes, i.e., 15-20 cm, 20-25 cm, 25-30 cm, 30-35 cm, 35-40 cm, and 40-45 cm. Sixty trees were selected for the estimation of fruit yield and ten trees were constituted under each DBH class. Only matured and fully ripened pods were chosen and examined for the purpose of fruit yield estimation. The tree parameters, i.e., The DBH, crown diameter, and height of the tree were all measured. All of the pods, even dropped pods, were tallied from each tree selected. From each sampled tree, 100 non-fallen fruits were randomly collected as sample for fruit yield estimation. The collected fruits were weighed fresh. The total fruit weight of a tree was computed by multiplying the fruit weight of this sample of pods with the total number of pods present on the tree. The equations for the estimation of fruit yield were developed by using DBH as the predictor or independent factor.

3.2.3 Tree selection

Table 3.1: Diameter classes, DBH, and no. of trees/diameter class of the selected trees of *Pongamia pinnata* under Punjab Conditions

Diameter class (cm)	Diameter at Breast Height (cm)	No. of trees/ Diameter Class
15-20	16.8, 16.9, 17.3,17.6, 18.2, 18.4, 18.7, 19.2, 19.5, 19.7	10
20-25	20.2, 20.6, 21.3, 21.8, 22.1, 22.6, 23.3, 23.8, 24.2, 24.6	10
25-30	25.2, 25.4, 26.3, 26.8, 27.2, 27.5, 28.2, 28.6, 29.2, 29.5	10
30-35	30.4, 30.7, 31.2, 32.6, 32.8, 33.4 33.7, 33.9, 34.1, 34.6	10
35-40	35.1, 35.6, 36.2, 36.7, 37.3, 37.6, 38.3, 38.7,39.2, 39.7	10
40-45	40.2, 40.6, 41.3, 41.8, 42.1, 42.6, 43.3, 43.8, 44.2, 44.6	10

3.2.4 Observations Recorded

3.2.4.1 Diameter at breast height (cm)

The girth value of the tree was taken at breast height (1.37 m) with the help of measuring tape and then converted into the diameter at breast height by the formulae, Diameter = Girth/π. The diameter was measured in centimetres.

3.2.4.2 Tree height (m)

The height of the tree was recorded using the Haga altimeter, an instrument based on trigonometrical principles, and it was expressed in metres.

3.2.4.3 Crown spread (m)

The spread of the crown of the tree was measured by projecting the edges of the crown of the tree to the ground and measuring the length along its widest diameter using a measuring tape. Crown spread was measured in metres.

3.2.4.4 Bole height (m)

The bole height of the tree was recorded using the Haga altimeter, an instrument based on trigonometrical principles, and it was expressed in metres.

3.2.4.5 Crown height (m)

The crown height of the tree was measured from the ground level to the point at the middle of lowest branch and the branches making a round crown using Haga altimeter. Crown height was measured in metres.

3.2.4.6 Crown length (m)

The length of the crown of the tree was measured vertically from the top point of the crown to the point at the middle of lowest branches making a round crown and the lowest branch on the bole using Haga altimeter. The crown length was measured in metres.

3.2.4.6 Fruit biomass (Kg)

The collected fruits were weighed fresh. The total fruit weight of a tree was computed by multiplying the fruit weight of a sample of pods from that tree with the total number of pods present on the tree.

3.2.5 Statistical analysis

Gomez and Gomoez (1984) procedure has employed for the statistical analysis of the present study with the help of the software Statistical Package for the Social Sciences Version 27 (SPSS Statistics) for the demonstration and evaluation of the results of the study. Five regression models were selected and tested to obtain the most accurate model to predict fruit biomass with respect to DBH. The following models were tested:

Linear Model : $Y=a+bX$

Power Model : $Y=aX^b$

Exponential Model : $Y=ae^{bX}$

Polynomial Model : $Y=aX^2+bX+c$

Logarithmic Model : $Y=a\ln(X)+b$

Plate 3.1: Roadside plantations, Hambran road, Ludhiana

Where,

Y = Dependent factor

X = Independent factor

a,b,c = Parameter

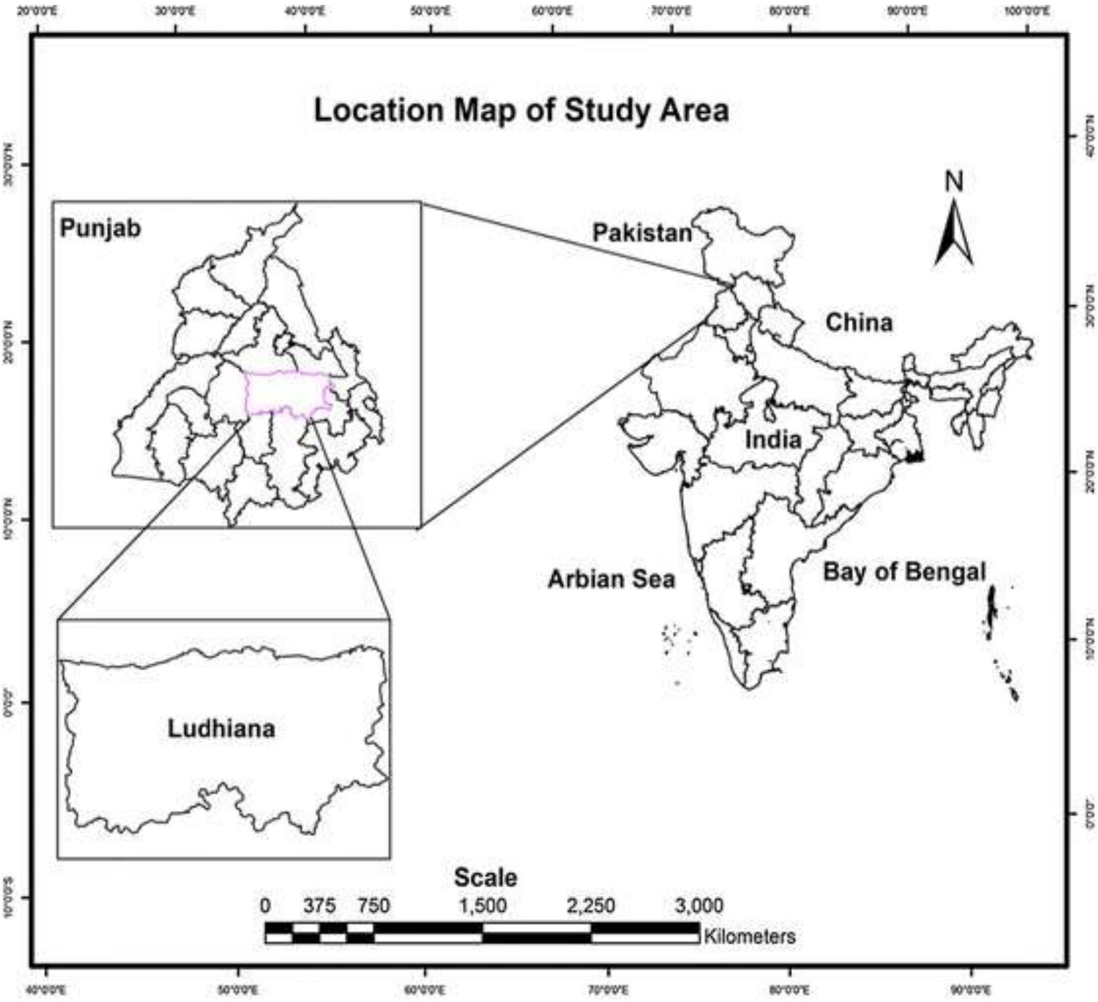

Fig. 3.2: Location map of study site

CHAPTER IV

RESULTS AND DISCUSSION

4.1 EXPERIMENT NO. 1

Name of Experiment: Study of phenological behaviour in *Pongamia pinnata* under Punjab conditions.

The findings of the experiment no.1 are presented under the following two main sub-headings:

4.1.1 Vegetative Phenology

4.1.2 Reproductive Phenology

4.1.1 Vegetative Phenology

The leaf bud bursting in *Pongamia pinnata* occurred twice during the entire research period (March, 2020 to February, 2021), i.e., in May when the day length is more and the temperature is high, and in August after the arrival of the monsoon. The maximum number of leaves were observed on the trees in October, and the minimum in April (Fig. 4.1). The young leaves took 25–35 days to get matured and the average age of the leaves was observed to be 150–250 days. The fall of the leaves began in November when the temperature and number of daylight hours started to decrease. Young leaves were appeared only during four months, i.e., May, June, August, and September in 2020. The number of mature leaves were increased from May, 2020 to October, 2020, but the trend reversed during the winter season.

Table 4.1: Vegetative phenophases of *Pongamia pinnata* under Punjab conditions

Vegetative phenophases	Month/No of days
Leaf bud bursting (month)	May and August
Leaf maturation time (days)	25-35
Average age of a leaf (days)	150-250
Maximum total leaves (month)	October
Leaf fall initiation (month)	November
Minimum total leaves (month)	April

Plate 4.1: Trees selected for phenological studies in PAU main campus, Ludhiana

Table 4.2: Monthly variation in vegetative phenology of *Pongamia pinnata* under Punjab conditions

Month	Average no. of young leaves/twig	Average no. of mature leaves/twig	No. of total leaves/twig
March, 2020	0	40	40
April, 2020	0	20	20
May, 2020	25	30	55
June, 2020	15	50	65
July, 2020	0	60	60
August, 2020	20	60	80
September, 2020	15	70	85
October, 2020	0	90	90
November, 2020	0	80	80
December, 2020	0	74	74
January, 2021	0	62	62
February, 2021	0	53	53

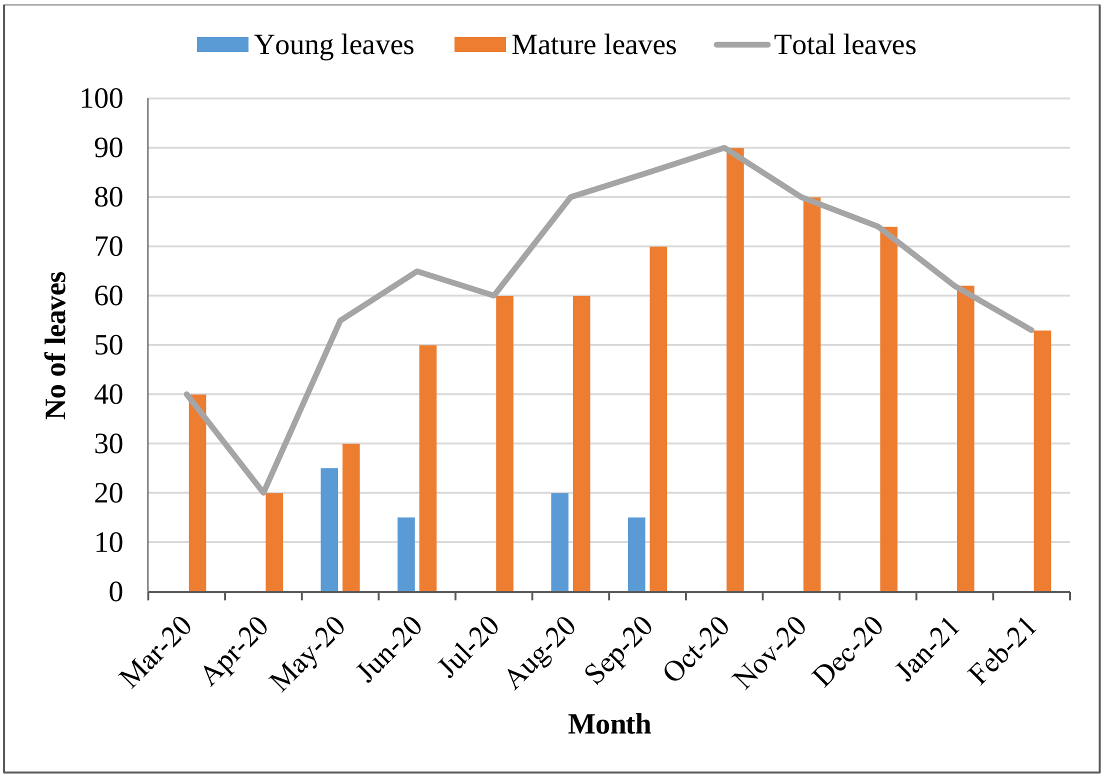

Fig. 4.1: Monthly variation in vegetative phenology of *Pongamia pinnata* under Punjab conditions

4.1.2 Reproductive Phenology

Floral buds first appeared at the end of April, and flowers appeared in May (Fig. 4.2). It was noticed from the observations that from the middle of May to the middle of June, *Pongamia pinnata* began to produce flower buds profusely (Plate 4.2). The flowering period from initiation to the completion was observed to be 28 days.

The new and young fruits were appeared in early June and got ripened (yellow colour) in 180 days. The fruits remained on the trees after ripening for 150 days before start falling in late April as the summer approached. The colour change of the pods from green to golden brown (harvesting stage) occurred within 270 days. From June, 2020 to late April, 2021, the pod development lasted 330 days. The reproductive phenological traits vary greatly from locality to locality in pongam trees, and the variations may be related to the tree's genetic effect as well as the ecological factors prevalent in its surroundings.

Table 4.3: Reproductive phenophases of *Pongamia pinnata* under Punjab conditions

Reproductive phenophases	Month/No of days
Flower initiation	Late April
Fruit formation	Early June
Length of reproductive phase (days)	330

Table 4.4: Monthly variation in reproductive phenology of *Pongamia pinnata* under Punjab conditions

Months	Average No. of flowers/twig	Average No. of fruits/twig
March 2020	0	4.90
April 2020	0	2.80
May 2020	40	0.00
June 2020	0	23.00
July 2020	0	21.00
August 2020	0	18.50
September 2020	0	15.10
October 2020	0	13.00
November 2020	0	11.20
December 2020	0	10.00
January 2021	0	7.90
February 2021	0	6.20

Plate 4.2: Flowering in *Pongamia pinnata* under Punjab conditions

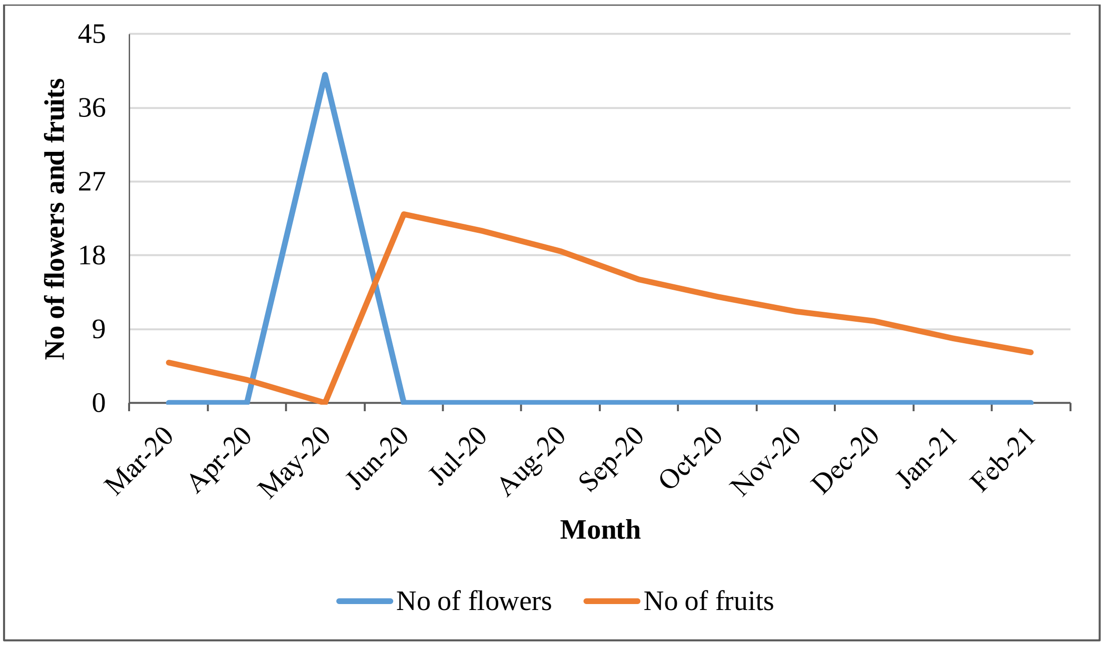

Fig. 4.2: Monthly variation in reproductive phenology of *Pongamia pinnata* under Punjab conditions

Monthly observations on fruits' maturation revealed that the fruit was light green in colour during the first month of its development and at the third month it was observed to be dark green in colour. It was yellowish-green in the fifth month. From the seventh month, while the colour was greenish-brown, which changed to light brown in the ninth month and finally changed to yellowish/golden brown in the eleventh month after anthesis (Plate 4.3).

Pongamia pinnata exhibited leaf flushing twice a year, i.e, first in summer conditions in May and second in rainy conditions in August. Increased photoperiod, temperature, minimal rain, and/or their combined effect may be the reason behind this behaviour. Physiologically, prolonged daylight hours and high temperature improves root water absorption, and leaf initiation (Borchert 1998). Summer leaf flushing is heavily influenced on the use of higher photoperiod months for maximum photosynthetic activity. In the current study, Leaf shedding was started in November and the end of winter coincided with the greatest amount of leaf shedding in all of the selected trees (April). Reduced soil moisture, photoperiod (day length), and temperature all influence the timing of leaf fall. Plants gain the ability to conserve water within themselves and maintain shoot turgidity as a result of leaf shedding during winter and early summer seasons.

The reproductive phase of pongam began with the initiation of flowering in the summer season, i.e., in May. The flower bud developed in late April as the mean temperature and daylight hours rose. This could be because of their increased response to temperature, in the study it was also observed that almost simultaneous emergence of flower buds and leaves.

The present results are in conformity with the findings of other workers (Bajpai *et al* 2015, Kumar *et al* 2015) who have also reported that flowering begins at the end of winter. Flowering during the dry season promotes flower visibility, increased pollination due to low leaf density, and increased insect activity. In the dry summer, all of the selected trees began to bear fruit. With the onset of the summer season, high temperatures generally promote the rate of fruit maturation and ripening, providing a good opportunity for dispersal, pathogenic attack prevention, and germination. However, the late maturation in *P. pinnata* indicated its independence from rains.

Table 4.5: Duration of phenophases in *Pongamia pinnata* under Punjab conditions

Phenophase	Total No. of days
Leaf fall period (Initiation to completion)	180
Leaf less period	0
Leaf-flush period (Initiation to completion)	60
Flowering period(Initiation to completion)	42
Fruiting period (Initiation to fruit ripening)	180
Change of colour of fruit (green to golden brown)	270
Fruit fall period (Initiation to completion)	150

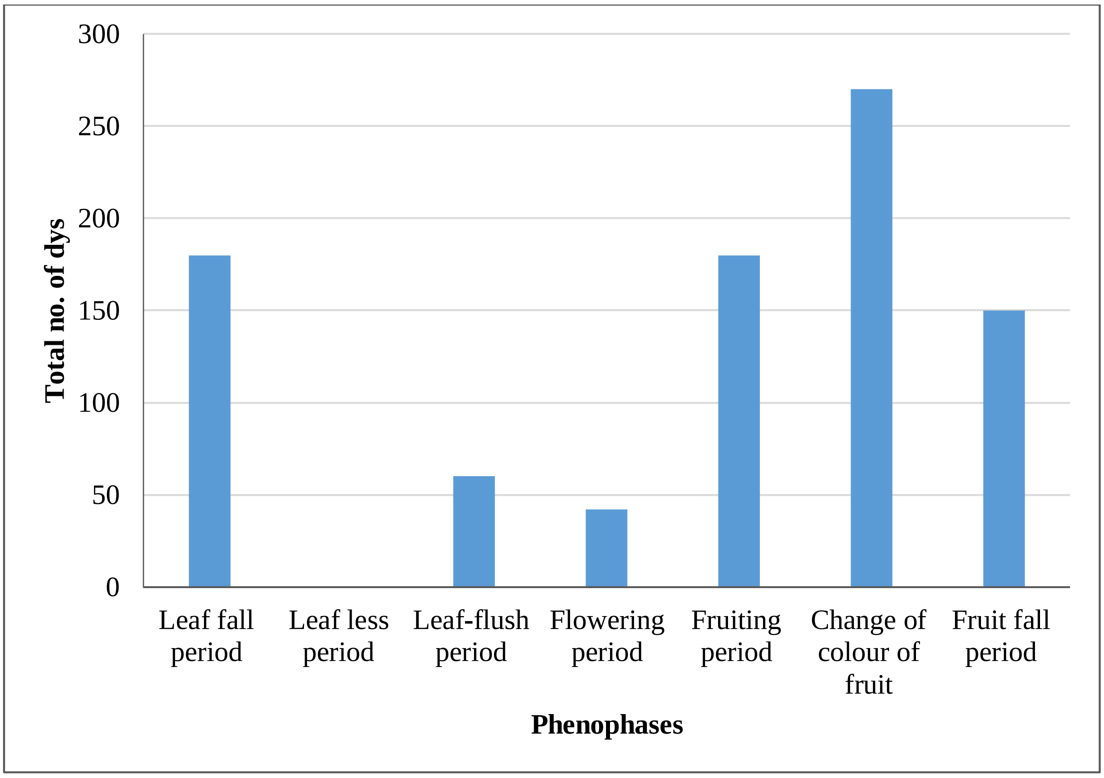

Fig. 4.3: Duration of phenophases in *Pongamia pinnata* under Punjab conditions

1st month 3rd month 5th month

7th month 9th month 11th month

Fallen pod

Plate 4.3: Pod development in *Pongamia pinnata* under Punjab conditions

In the current study, the pod development took nearly 330 days after fruit setting. On the other hand, another research from southern part of the country conducted in Tamil Nadu found that *P. pinnata* requires only 189 to 220 days following fruit setting (Srimathi *et a*l 2013), suggesting that pod development and other morphological traits will be highly genetically variable, and that these qualities are highly reliant on the environmental and meteorological factors. In the ninth month, the fruit parameters, i.e., pod length pod width were found to be at their maximum indicating that the ninth month after anthesis (February) is the best time to harvest the fruits.

4.2 EXPERIMENT NO. 2

Name of Experiment: Estimation of fruit yield in *Pongamia pinnata* under Punjab conditions.

4.2.1. Linear and Non-Linear Functions for Fruit Biomass with DBH

Linear and non-linear models by using fresh fruit biomass as dependent factor and DBH as an independent factor are given in Table 4.6. The polynomial/quadratic function Fruit biomass = $-0.011(DBH)^2+2.692(DBH)-37.112$ with maximum Adj. R^2 value of 0.911 and minimum standard error of estimation value of 5.467 was obtained to be the most accurately fit model to predict fruit biomass. The linear function Fruit biomass = 2.026(DBH)-27.955 is also a very good equation as it is having the same Adj. R^2 value but with a slightly more standard error of 5.470. The exponential function Fruit biomass = $2.325e^{0.081(DBH)}$ with minimum Adj. R2 value of 0.843 and maximum standard error of estimation value of 6.301 was the least fit in all the analysed functions.

Table 4.6: Linear and non-linear functions for fruit biomass with DBH of *Pongamia pinnata* under Punjab conditions

Fresh fruit biomass	SE of estimate	Adj. R^2
FB= 2.026(DBH)-27.955	5.470	0.911
FB= 56.595ln(DBH)-157.170	5.813	0.900
FB= $-0.011(DBH)^2+2.692(DBH)-37.112$	5.467	0.911
FB= $0.010(DBH)^{2.336}$	6.246	0.895
FB= $2.325e^{0.081(DBH)}$	6.301	0.843

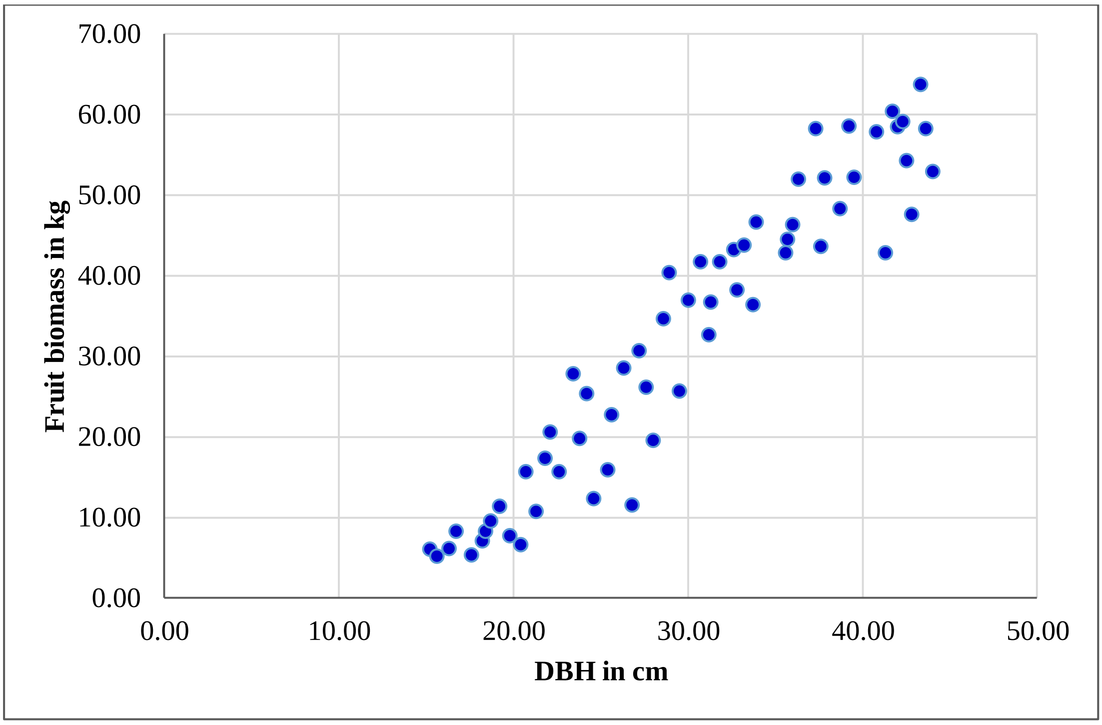

Fig. 4.4: **Scatter plot of fruit biomass by DBH of *Pongamia pinnata* under Punjab conditions**

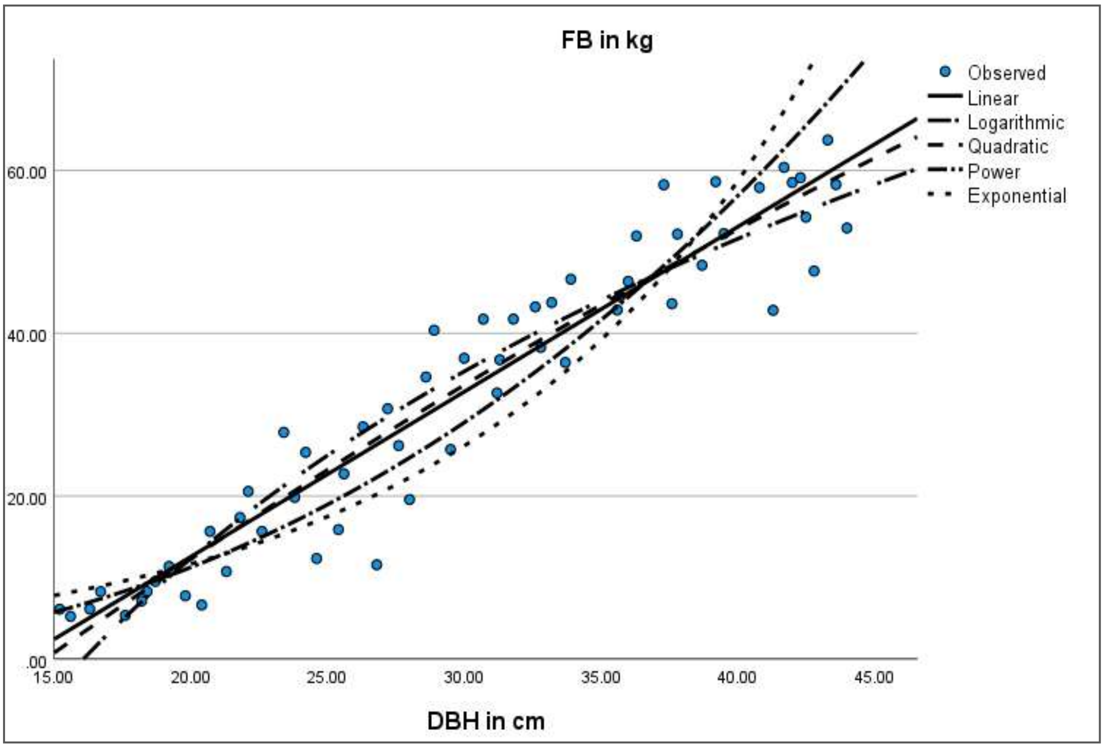

Fig. 4.5: **Linear and non-linear functions for fruit biomass (FB) with DBH of Pongamia pinnata under Punjab conditions**

From the results it is very clear that the adjusted R^2 values for all the tested equations are appreciably higher, which reflects the appropriate reliability of all these models. But the polynomial/quadratic function with maximum Adj. R^2 value of 0.911 and minimum standard error of estimation value of 5.467 was obtained to be the most accurately fit model to predict fruit biomass as compared to other models tested.

4.2.2. Growth Characteristics of Trees in Different Diameter Classes

The crown, stem, and roots are the three major sections of a tree, which is the heaviest of all flora on the globe. The crown is supported by a trunk, and both are maintained by the extensive and large root system. The genetic makeup of a tree species, as well as ecological and climatic factors impact its development.

Table 4.7: Minimum and maximum values of fruit biomass, DBH and crown width of *Pongamia pinnata* under Punjab conditions

Parameters	Minimum value/tree	Maximum value/tree
Fruit total biomass (kg)	5.23	63.75
Diameter at breast height (cm)	15.20	44.00
Crown width (m)	3.21	10.00
Tree height (m)	6.18	22.23

4.2.2.1. Tree height

The average height of the selected individuals in the diameter range of 40-45 cm was found to be the highest (20.34m) and 15-20 cm was the lowest (6.82m). The difference in average heights of trees was found to be maximum between 20-25cm and 25-30 cm diameter classes while it is minimum between 35-40 cm and 40-45 cm diameter classes.

Table 4.8: Height of tree against DBH of *Pongamia pinnata* under Punjab conditions

Diameter class (cm)	Mean height (m)
15-20	6.82
20-25	9.11
25-30	13.47
30-35	15.26
35-40	19.25
40-45	20.34

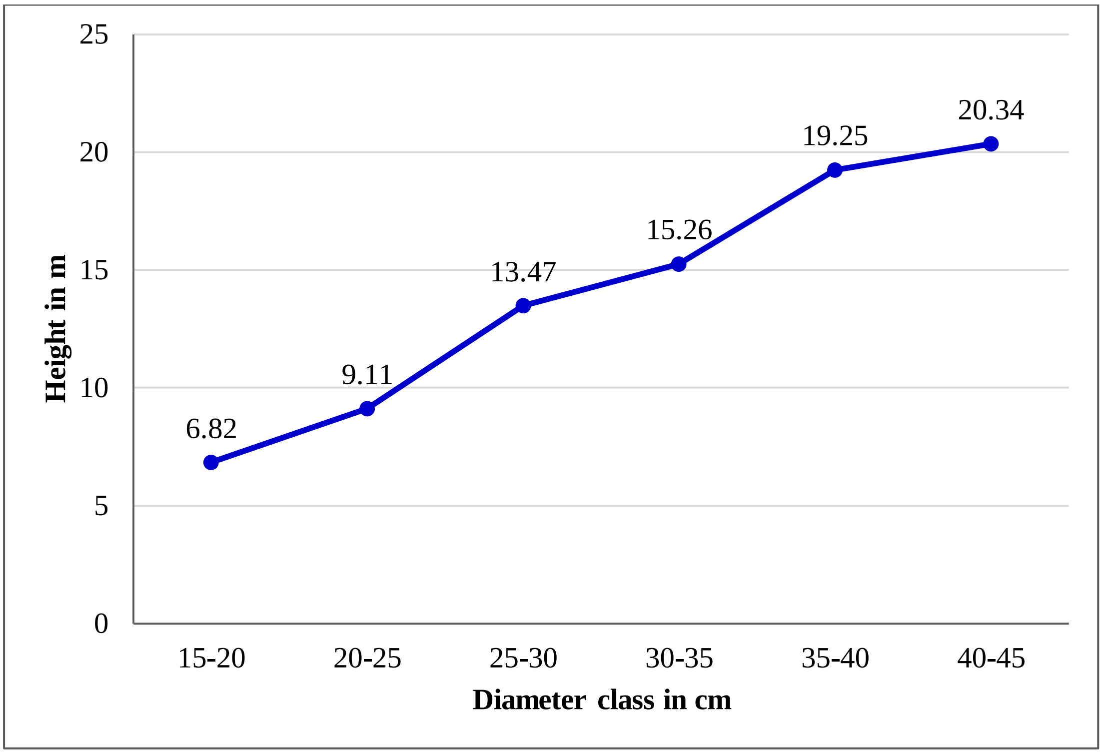

Fig. 4.6: Height of tree against DBH of *Pongamia pinnata* under Punjab conditions

4.2.2.2. Fruit weight

The average fruit weight of the selected individuals in the diameter range of 40-45 cm was found to be the highest (55.57 kg) and 15-20 cm was the lowest (7.52). The difference in mean fruit weights of trees was found to be maximum between 25-30cm and 30-35 cm diameter classes while it is minimum between 35-40 cm and 40-45 cm diameter classes.

Table 4.9: Fruit weight against DBH of *Pongamia pinnata* under Punjab conditions

Diameter class (cm)	**Mean fruit weight (kg)/tree**
15-20	7.52
20-25	17.21
25-30	25.60
30-35	39.82
35-40	49.90
40-45	55.57

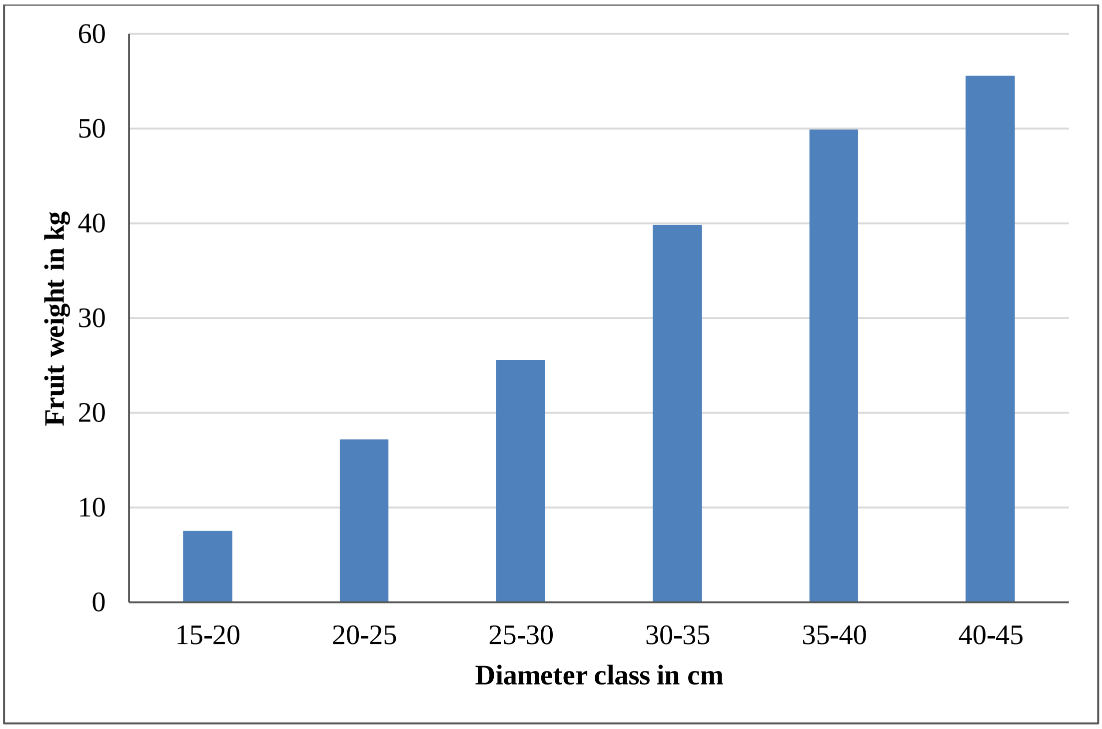

Fig. 4.7: Fruit weight against DBH of *Pongamia pinnata* under Punjab conditions

4.2.2.3. Crown spread

The mean crown width of the selected individuals in the diameter range of 40-45 cm was found to be the highest (8.83 m) and 15-20 cm was the lowest (3.67 m). The difference in crown spread of trees was found to be maximum between 25-30cm and 30-35 cm diameter classes while it is minimum between 35-40 cm and 40-45 cm diameter classes.

Table 4.10: Crown spread against DBH of *Pongamia pinnata* under Punjab conditions

Diameter class (cm)	Crown spread (m)
15-20	3.67
20-25	4.23
25-30	4.65
30-35	7.41
35-40	8.59
40-45	8.83

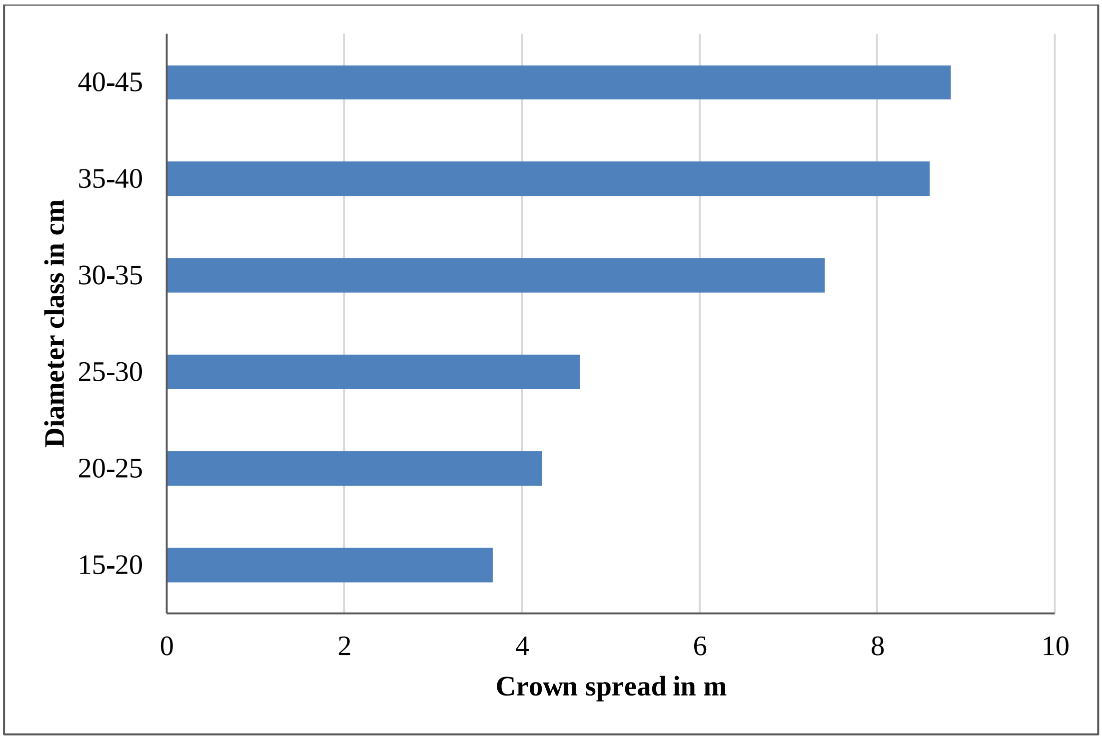

Fig. 4.8: Crown spread against DBH of *Pongamia pinnata* under Punjab conditions

All the parameters measured, i.e., tree height, fruit weight, and crown spread are increasing with increasing DBH of trees. The results clearly indicated that the rate of their increment is maximum when their diameter was in the range of 20 cm-35cm, while minimum after attaining 40 cm diameter. The tree height increment curve from the diameter class 20-25 cm to 25-30 cm and 30-35 cm to 35-40 cm were found to be steep while that after 35-40 class was shallow. Fruit weight showed a steady increment with the diameter and a noticeable increment have observed between 25-30 cm and 30-35 cm diameter classes. Crown spread also showed a sharp increase between 25-30 cm and 30-35 cm diameter classes while the difference in crown spread between 35-40 cm and 40-55 cm diameter classes was relatively less.

CHAPTER V

SUMMARY

The present investigation entitled “Phenological behaviour and development of fruit yield prediction models in *Pongamia pinnata* (L.) Pierre under Punjab conditions” was aimed to study different phenophases of the *Pongamia pinnata* and to record the fruit yield in order to develop fruit yield prediction models based on DBH under Punjab conditions.

In the first experiment, leaf initiation, leaf maturity, leaf fall, flowering, fruit initiation, and fruit fall were all examined for *Pongamia pinnata* within the main campus of Punjab Agricultural University, Ludhiana, Punjab from March, 2020 to February, 2021. Morphologically healthy pongam trees were selected using simple random sampling technique. Ten adult individuals (>30cm GBH and >6m height) were permanently selected for recording the phenological observations. Four main branches (from four directions) were chosen from each selected tree, and four twigs from each branch were tagged. The selected trees were used for studying leaf initiation, completion, leaf fall, flower phenology, and pod development and observations were recorded on a monthly basis. The study found that a short low-temperature dry period, adequate winter rain, and temperature rise are the triggering factors for summer leaf flushing, as well as increased soil water availability for second leaf flushing during rains. But, it is very important to note that the phenological behaviour of pongam was largely influenced by the resources that are available in its proximity. That is why some trees growing along the water resources were exhibited semi-evergreen nature. The leaf flushing was observed in two times in a year, i.e., during May, the beginning of summer season, and in August, the rainy season. The leaf flushing in summer and flowering were found to be almost simultaneous and increased pollination accessibility and engagement during that time promoted significantly higher rate of production of pods. The results revealed that, the pod took nearly 330 days after fruit setting to fall, but the pod measurements were found to be attained maximum in the ninth month of pod development, indicating that February is the best time to harvest the fruits. Despite the fact that ripening of fruits during the rainy season increased their dispersal and germination success, pongam’s late maturation indicated its independence from rains and thus it cannot be recommended as a suitable tree species for climate change research.

For the second experiment, the trees were selected using random sampling method from the roadside plantations, Hambran road, Ludhiana, based on their girth at breast height. The values were converted to DBH and the trees were divided into six classes according to that. Sixty trees were selected for measurements of fruit yield and other tree parameters and ten tress were constituted under each DBH class. Only matured and fully ripened pods were chosen and examined for the purpose of fruit yield estimation. The tree parameters, i.e., The DBH, crown diameter, and height of the tree were all measured. The collected pods were weighed fresh immediately. The total fruit weight of a tree was computed by multiplying the fruit weight of a sample of pods from that tree with the total number of pods present on the tree. The equations for the estimation of fruit yield were developed by using Diameter at breast height as the predictor or independent factor. A total of five models, viz., linear, power, exponential, polynomial/quadratic, and logarithmic, were tested for the best fit model. The polynomial/quadratic function Fruit biomass = $-0.011(DBH)^2+2.692(DBH)-37.112$ with maximum Adj. R^2 value of 0.911 and minimum standard error of estimation value of 5.467 was the best fit to predict fruit biomass. The exponential function Fruit biomass = $2.325e^{0.081(DBH)}$ with minimum Adj. R2 value of 0.843 and maximum standard error of estimation value of 6.301 was the least fit. All the tree parameters measured, i.e., tree height, fruit weight, and crown spread were found to be increasing with increasing DBH and the rate of their increment was maximum in 20-35 cm diameter range and minimum after attaining 40 cm diameter.

CONCLUSION

The study discusses the various phenophases of *Pongamia pinnata* under Punjab conditions. Summer leaf flushing (along with flowering) begins after a three month dry period with low temperatures (January–March) and adequate winter rain (January). The initiation of flowering during the dry season aids in the production of maximum fruits due to increased pollination opportunities. *P. pinnata*'s late maturation indicates its independence from rain. The polynomial/quadratic function Fruit biomass (kg) = $-0.011(DBH)^2+2.692(DBH)-37.112$ with maximum Adj. R^2 value of 0.911 and minimum standard error of estimation value of 5.467 was the best fit to predict fruit biomass.

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