KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI

COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

FACULTY OF AGRICULTURE

DEPARTMENT OF HORTICULTURE

PHENOLOGY AND SEED GERMINATION IMPROVEMENT OF TWO IMPORTANT TREE SPECIES IN THE MOIST SEMI-DECIDUOUS FOREST ZONE OF GHANA

BY

JAMES OPPONG AMPONSAH

APRIL, 2016

PHENOLOGY AND SEED GERMINATION IMPROVEMENT OF TWO IMPORTANT TREE SPECIES IN THE MOIST SEMI-DECIDUOUS FOREST ZONE OF GHANA

By

JAMES OPPONG AMPONSAH

A THESIS SUBMITTED TO THE SCHOOL OF RESEARCH AND GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY (KNUST), KUMASI, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF PHILOSOPHY (SEED SCIENCE AND TECHNOLOGY)

APRIL, 2016

DECLARATION

I hereby declare that this submission is my own work towards the MPhil. and that, to the best of my knowledge it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

....

JAMES OPPONG AMPONSAH DATE

(STUDENT)

....

DR. B. K. MAALEKU DATE

(SUPERVISOR)

....

MR. PATRICK KUMAH DATE

(CO- SUPERVISOR)

....

DR. FRANCIS APPIAH DATE

(HEAD OF DEPARTMENT)

DEDICATION

To my dear wife Faustina Oppong and son Jayden Oppong for their patience and understanding when I had to scale down my time and attention for them when working on this thesis.

ACKNOWLEDGEMENT

My heartfelt gratitude goes to my supervisors, Dr. B. K. Maaleeku and Mr. Patrick Kumah of the Department of Horticulture, Kwame Nkrumah University of Science and Technology for their direction, encouragements, and supervision without which the work would not have been accomplished. I am also grateful to Dr. S. Adu Bredu and Dr. J. Mireku Asomaning of the Council for Scientific and Industrial Research- Forestry Research Institute of Ghana (CSIR-FORIG) for their immense support and vital suggestions.

My special thanks go to the International Tropical Timber Organization (ITTO) in Japan for funding the field work under the Freezailah Fellowship Program. Thanks to Mr. Emmanuel Ze Meka, Executive Director and Dr. Chisato Aoki, ITTO Fellowship Programe Coordinator for their kind support and assistance.

I am truly grateful to Mr. Paul Asuming, Mr. Samuel Boateng and the entire staff of the Bobiri Forest Research Station of CSIR-FORIG for their enormous support and assistance during field data collection of the study. I cannot overlook the assistance of Mr. Kwaku Duah and the entire staff at the National Tree Seed Center (NTSC) of CSIR-FORIG for their supportive role in carrying out this work.

To my wife, Faustina, and son Jayden, I say thanks a million times for their invaluable encouragement and love from the time I considered the idea to carry out this study till this moment.

To the Almighty God Jehovah, I express my innermost appreciation for his goodness and mercies all this while.

ABSTRACT

Understanding the phenology and seed germination improvement techniques of native forest tree species is crucial for their conservation and the restoration of degraded forest areas. This study examined the reproductive phenology and the effect of four chemical and physical seed germination improvement techniques on two indigenous forest tree species namely; *Terminalia superba* and *Terminalia ivorensis*. The reproductive phenology was observed and documented over 24 months. The effect of chemical and physical scarification on seed germination were evaluated under ambient temperatures for 36 days. Period and intensity of Leaf flushing (LF), Flowering (FL), Fruiting (FR) and Seed dispersal (SD) pheno-phases of 115 selected tree stands of the species were monitored and scored using the widely adopted BBCH system of coding plant phenology. Leaf flushing (LF) in both species coincides with the onset of the wet season in April-July, and it is followed by flowering in August-September. Fruiting and seed dispersal pheno-phases occurred between October-February. A strong positive correlation ($r = 0.7325$, $P < 0.05$) was found between the highest Leaf flushing (LF) percentage and average monthly rainfall (RA). The strongest negative correlation was established between percentage of Fruiting (FR) individuals in both species and mean monthly maximum temperatures (TE^{mx}). Chemical scarification (soaking in H_2SO_4 2g/l for 20 minutes prior to sowing) improved seed germination in both species by more than 50 percent. Results indicate that *T. superba and T. ivorensis* undergo a consistent and synchronized annual reproductive cycle dependent on temperature and rainfall. The results further suggests that large scale climatic fluctuation can affect their reproductive and vegetative phenology.

TABLE OF CONTENT

LIST OF TABLES

TITLE PAGE NUMBER

..

LIST OF FIGURES

TITLE PAGE NUMBER

..

LIST OF PLATES

LIST OF ABREVIATIONS

Abscisic acid	ABA
Association of Official Seed Analysts	AOSA
Biologische **B**undesanstalt, and **Ch**emical Industry	BBCH
Centimetre	cm
Coefficient of variation	cv
Degree Celcius	°C
Degrees of freedom	df
Et al (and so on)	et al.
Food and Agriculture Organization	FAO
Forestry Research Institute of Ghana	FORIG
Global Phenological Monitoring	GPM
Gibberellic acid	GA3
Gram	g
Gram per litre	g/l
International Society of Biometeorology	ISB
International Seed Testing Association	ISTA
Mean germination time	MGT
Milligram per litre	mg/l
Millilitre	ml
Millimetre	mm
Moisture content	MC
Percentage	%
Relative humidity	RH
Standard error of the difference	s.e.d
The World Conservation Union	IUCN
Vigour index	VI

CHAPTER ONE

1.0 INTRODUCTION

The rate of decline of forest cover in most tropical countries is very alarming. In sub-Saharan Africa, forests are still disappearing at a rate of nearly one percent a year (FAO, 2005) despite the many reforestation and conservation programs. Climate variability coupled with the unprecedented increase in human population in recent decades has brought about the excessive use of land for agricultural purposes, housing, roads and etc., thereby increasing biotic pressure on native forests (Menzel and Sparks, 2006). It has been observed that deforestation rate has declined in some countries during the last decades only because there is little left to destroy (Schmidt,
2000).

For various reasons such as logging and clearing for cash crop cultivation, the rainforest in Ghana has dwindled from 8.2 million ha to 1.62 million ha over the past 100 years with a deforestation rate ranging from 0.77% to 1.4% per annum. Currently only about 20% of the original forests remain (MESTI, 2010) with these forest fragments mostly surrounded by subsistence and agricultural lands most of which are devoid of trees.

Besides the negative impact of deforestation on the lives of millions of people in urban and rural communities, much of the world's biodiversity especially in the tropics is being irreversibly lost through extinction caused by the destruction of natural habitats (Wilson, 1988). It is estimated that about 200 tropical tree species in West-Central Africa are considered to fall into the category of being 'near- threatened' to 'critically endangered' as determined by the World Conservation Union (IUCN, 2008). The increasing demand for wood resources especially has made it imperative that efforts are made towards the expansion of the timber resource base. For example, the estimated

wood requirement of the timber industry in Ghana is approximately 4.0 x 10^6 m^3 yr^{-1}; far in excess of the annual allowable cut of 1.0 x 10^6 m^3yr^{-1} from the natural forest estates (Ofosu-Asiedu *et al*., 1997).

According to Schmidt (2000), a major solution to the problem of deforestation is to raise new trees and forests. Raising trees and preserving their seeds besides curbing deforestation is also a means of combating desertification, safeguarding the environment and conserving biodiversity. Planting trees is globally considered as an effective measure to mitigating the negative impact of climate change. Trees not only bind the greenhouse gas carbon dioxide, they also counteract desertification and soil erosion (Grainger, 1993).

For this reason many governments in the tropics have taken considerable steps towards restoring the dwindling forest resources. In Ghana for instance, the Presidential Special Initiative on Forest Plantation Development launched in September 2001, aimed at planting 20,000 hectares of forests annually throughout the country up to the year 2020 with fast growing indigenous and exotic tree species (Cobbinah *et al*., 2001). The total forest plantation estate in Ghana, including private plantations is estimated at 160,000 ha (FAO, 2005).

Reversing deforestation and reclaiming lands degraded by deforestation is an enormous challenge that will require the planting of large numbers of seedlings which in turn implies an increased demand for forest tree seeds. Seed propagation remains the principal mode of propagation of forest trees in the temperate as well as in the tropical regions.

Noteworthy is the fact that, the continuous supply of high quality forest tree seeds is essential for the success of any reforestation programme (Sacande and Pritchard, 2004*).* For several species of forest trees, shortage of seeds, difficulties in collection, short viability, problems of extraction, prolonged dormancy and other handling difficulties limit their use in plantation and reforestation programs (Bawa and Hadley, 1991).

According to Quedraogo *et al.* (1999), more than 70% of trees in tropical ecosystems produce recalcitrant seeds which are difficult to collect, process and store. It has also been observed that very little information is available on the phenology, seed handling techniques, dormancy breaking methods, and optimum conditions for storage and germination in most indigenous tropical tree species (Brookman-Amissah, 1997). Bawa *et al.* (1990), revealed that information on the reproductive phenology for many tropical tree species is usually scarce and this limits the development and implementation of management strategies for these species. This was probably one of the reasons why forest plantations established in the tropics rely mostly on exotic species whose biology, phenology and seed handling procedures were known. Forest restoration for biodiversity conservation, watershed protection and carbon sequestration require detailed knowledge of forest tree phenology (FORRU, 2006). Mireku (2009) also reiterated that for indigenous tree species to be used in reforestation and conservation programmes in Ghana, it is important to generate knowledge on their phenology, physiology and identify the appropriate seed handling and storage techniques for the species.

Two important indigenous tree species in the semi deciduous forest zone of Ghana namely: *Terminalia superba* (Oframo) and *Terminalia ivorensis* (Emire) have been

selected for this study. Both species (*T. superba* and T. *ivorensis)* have been classified as vulnerable with decreasing population trends according to the IUCN Red list of Threatened species (IUCN, 2008).

The study is aimed at contributing to existing scientific information on the phenology and seed germination improvements techniques of *T. superba* and *T. ivorensis* The specific objectives of the stud were to:

1. record and document the periodically recurring reproductive phenology of the selected species and detect any interrelationship between their phenology and microclimate variables such as temperature, and rainfall; and
2. devise an effective method for breaking dormancy in the seeds of the species to improve germination and seed viability.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 NATURE OF PHENOLOGICAL OBSERVATION

Leith (1974), defines phenology as the study of the timing of recurring biological events in the animal and plant world, the causes of their timing with regard to biotic and abiotic forces and the interrelation among phases of the same or different species. Plant phenological studies involve a careful observation and documentation of the timing of recurring life cycle events including leaf formation and fall, flowering, fruiting and seed dispersal. The task of studying plant phenology is to observe and record the periodically recurring vegetative or reproductive stages and to study the regularity and dependency of the yearly cycles of development on environmental conditions (Koch *et al.,* 2004). The modern discipline of phenology can be traced to the observations of Robert Marsham in Norfolk, England in 1736 and reached a peak of interest in the first half of

the 20th century. In recent decades there has been a resurgence of interest in plant phenology since data from studies on phenological changes are extensively utilized as indicators of global change (Post *et al.* 2001; Fitter and Fitter; 2002 and Menzel and Sparks, 2006).

Leaf unfolding, flowering, fruit ripening, leaf senescence, seed dispersal and dormancy are all examples of phenological events (Rathcke and Lacey, 1985; Leith, 1974). It is a periodic phenomenon in plants that are tied to periodic environmental changes (Schwartz, 2003). Observations of the date of particular pheno-phase (leaf emergence, flowering, fruiting, leaf senescence and the like) for species in a given locality are recorded often in conjunction with weather data. Occasionally these observational records are collated and available in computerized databases (PolteRudolf, 1993) but more often the data are scattered in relatively obscure publications or local natural history journals. Although ecologists have made use of such long term data records, their full potential has not been exploited. These historical records are becoming increasingly important as we begin to investigate the ways that global change may alter the patterns of seasonality in the temperate and the tropics

2.2. IMPORTANCE OF PHENOLOGICAL OBSERVATION

Phenological observations are some of the most sensitive data in identifying how plant species respond to regional climate conditions and to climatic changes. Therefore, phenology has emerged recently as an important focus for ecological research (Schwartz, 1999; Archerti 2013). Phenological information is important in monitoring all aspects of an ecosystem, therefore becoming essential in studying the dynamics of plant communities. It can therefore be used to devise a relationship between climate and growing periods of plants of an area, and such type of studies are essential for planning

vegetation regeneration, reforestation of degraded areas, and conservation of rangeland and forests (Menzel and Sparks, 2006).

Phenology is a useful indicator of global climate change because it integrates climate signals over a sustained period of time and it is easily measured. Changes in the timing of plant and animal phenology such as leaf-out, flowering, insect emergence, and migration are widely recognized as some of the most sensitive biological responses to climate change (Parmesan and Yohe 2003;Root *et al*, 2003; IPCC 2007; Cleland *et al.*, 2012). These changes are ubiquitous, and the integral role phenology plays in ecosystems ensures that phenological change will affect nearly all ecological relationships and processes (Bellard *et al.*, 2012).

One of the important purposes of phenological observations is to improve our understanding of the relationships between meteorological variables and associated biological responses. Understanding these relationships is crucial, not only for predicting ecosystem responses to climate change but also in identifying the carbonuptake period of forest stands and for examining the seasonal exchanges of water and energy between the land surface and the atmosphere (Chen and Xu, 2012).

Phenological study is an important aspect of tree genetic resource conservation for agro forestry management purposes. Agriculture and forestry sciences have applied phenological data for the scheduling of agricultural work, timing of seed collection in forests and the selection of suitable crops and cultivars. Reliable phenological information guides the timing and methods of many fundamental agricultural practices, such as when, where, and what to plant; when to apply pesticides, herbicides, and fertilizers; and when to harvest (Devineau 1999; Lavalle *et al*. 2009;Ventrella *et al.*

2012; Holzkamper *et al*., 2013). For example, phenology-based predictive models are regularly utilized for integrated pest management work, where pest activity is predicted and treated based on coupled plant phenology and growing degree models (Herms, 2004).

Walther (2010) found that global climate change has increased the length of the growing seasons for some forest species in temperate regions by as much as 12-18 days over the last two decades which includes an earlier onset of the growing season about 2 and a half days per decade in Europe. Researchers are then using those data to predict changes in the abundance and distribution of species in response to coming decades of climate change, with associated implications for ecosystem processes and conservation (Morin *et al.,* 2009).

Changes in phenology are affecting the abundance and distribution of species (MillerRushing *et al.,* 2010), the functioning of ecosystems, such as carbon cycling (Richardson *et al*., 2010), and ecosystem services, such as pollination (McKinney *et al.,* 2012). Cleland *et al.,* (2012) assembled data for 57 plant species across 24 sites and found that species that did not phonologically track inter annual climate variation declined in population performance (that is in measures of biomass, percent cover, number of flowers, and growth). Thus it may be possible to predict species vulnerability to climate change based on the presence, magnitude, or direction of its phenological response although the generality of this pattern remains unclear (Willis *et al.,* 2010).

Pioneer studies have consisted of transfer experiments, showing that phenology and especially leaf bud burst will be affected by future climate change (Beuker, 1994). However, the temperature increase in these experiments was often not realistic regarding the climate predictions for the future. During the last decade, several

experimental works have been conducted to study the impact of global climate change on species phenology. Most of these studies have been conducted on herbaceous species and the intra specific variability of response has rarely been studied (Doi *et al.*, 2010).

Phenological studies can inform us about the timing and duration of resource availability in ecological communities including, when pollen and nectar are available to pollinators, when fruits are available to fruit eating animals, when leaves are available for herbivorous insects and mammals and whether plants must compete with each other for the services of pollinators and seed dispersers (Lechowicz, 2003).

Some studies have shown experimentally that germination, flowering and leaf production out of season caused low survival of seedlings (Forest and Miller, 2010), low seed production (Augspurger, 1982), and a high predation rate (Aide, 1992). It is certainly conceivable that the schedule for these events is important on survival and reproductive success of forest trees. The timing of phenological events can be quite sensitive to environmental changes. According to Haggerty *et al*., (2008), phenological observation is therefore an integrative measure of the conditions of the physical, chemical and biological environment. Thus phenology is probably the simplest and most cost effective means of observing the effects of physical environmental changes on plant communities, and as results, phenology has become an important tool in global change research (Menzel and Sparks, 2006).

2.3 PRINCIPLES OF PHENOLOGICAL OBSERVATIONS

Phenological observations do not usually require costly equipment as the main ‘instrument’’ for monitoring environmental conditions is the plant itself. Indispensable

is the observation platform, observation guidelines and binoculars for large trees (Koch *et al*., 2004). In 1993 the Phenological Study Group of the International Society of Biometeorology (ISB), started a new initiative called Global Phenological Monitoring (GPM). Their main objectives among others were to form a global phenological back bone with a standard observation protocols, link 'local' Phenological networks and to encourage establishment and expansion of phenological networks throughout the world (Bruns *et al*., 2003).

The most important precondition to get homogeneous comparable data is the exact definition of the phenological phases. Attention should be paid to making sure that the site to be observed is a representative of the whole observation area. According to the GPM plants chosen should meet certain criteria such as easily recognizable phenological phases, sensitivity to humidity, temperature and broad geographic distribution (GPM Observation Protocols, 2003). Several different types of digital camera systems have been used across a range of sites to record high frequency phenological images. A test using 11 different cameras at a deciduous forest in South America showed that the choice of camera and image format did not make large differences in phenological recording (Sonnentag *et al.*, 2012).

2.4 PLANT PHENO-PHASES

There is considerable variation among flowering plants species with regard to when and how rapidly seasonal events occur. However, the generalized plants phenological events sequences as summarized by Hagerty (2008) are as follows; leaf bud burst, first full leaf, first flower, peak flowering, last flower, fruit maturity, seed dispersal leaf senescence and abscission. Newstrom *et al.* (1994) were the first to provide a systematic

framework for the classification of tropical tree phenology. Because many terms had multiple connotations and a number of terms were used to indicate the same phenomenon, they selected and explicitly redefined terms for phenological patterns or pheno- phases. For example the word 'seasonal' means the temporal association of an event with recognizable climatic season. Thus changes in flowering species or the proportion of flowering individuals during a year cannot be called seasonal, when association between the phenological event and a particular climatic interval is not clear.

2.5 FACTORS INFLUENCING PHENOLOGICAL CHANGES

Studies from different parts of the world have shown that climatic factors are mainly responsible for vegetative and reproductive phenology at both community and species level in forest trees. Water stress is most frequently cited as a primary environmental factor responsible for the timing of phenological events. However, various phenological events are triggered by rainfall, water availability, temperature, photoperiods, CO_2 levels and the duration of dry seasons (Singh and Kushwaha, 2005).

Individuals (genes, age) and environmental factors (weather and climate conditions in the micro and macro-scale, soil condition, water supply, diseases, competition etc.) influence the development of plants. They can be viewed as integrative measurement devices for the environment. The seasonal cycle of plants however is greatly influenced by temperature, photoperiod and precipitation (Borchert, 2005).

2.5.1 Environmental Factors Affecting Phenology

2.5.1.1 Precipitation/rainfall

Several authors have shown that water deficit or availability tends to significantly influence senescence, leafing, flowering, leaf fall and seed dispersion (Aronson *et al*., 1992). The effect of water deficit (as a results of precipitation/rainfall) on phenology and yield may also depend on whether they occur during the vegetative or reproductive phases of growth (Lilley and Fukai 1994; Nam *et al.*, 2001) In some cases, phenological responses to water deficits disrupt reproduction in trees. Christensen *et al.* (2007) have shown that decreased water availability is more likely to affect tree phenology than other factors.

2.5.1.2 Temperature

Warmer temperatures generally accelerate plant development (Zavaleta *et al*., 2003; Badeck et *al.*, 2004) although responses can vary among groups of plants for example grasses and forbs. Changes in temperature may have indirect effect on water availability both via changes in transpiration and perhaps via changes in precipitation although this is more likely to be variable. Temperature will affect plant growth and phenology through changes in the photosynthetic rates, respiration, and/or transpiration rates. An increased temperature in boreal regions will generally increase plant growth whereas plants at lower latitudes will generally slow down growth
(Korner, 2006).

There is still a lack of understanding of how the phenology of tropical tree species is influenced by temperature, e.g. whether there is a temperature threshold for plant activity under warm tropical climates (Clark, 2007). Moreover, phenology in tropical

trees is generally considered to be water or light dependent (Morellato *et al.* 2000; Borchert *et al.* 2005; Singh and Kushwaha, 2005). There are suggestions that climatedriven models are applicable for predicting plant phenology in the tropics (Borchert *et al.* 2005; Gazal *et al.*, 2008) and that phenology in tropical biomes may fail to be a useful indicator of global warming (Borchert *et al.*, 2005).

It may also be important to distinguish between air and soil temperature, as the two can have different effects on plant growth, and may vary asynchronously. Soil temperature has profound effects on root growth and respiration. In perennials, root growth, mortality and respiration are sensitive to soil temperature, with root respiration increasing by a factor of 1.5-3 for 10^{o}C increase in temperature (Pregitzer *et al.*, 2000).

2.5.1.3 CO_2 Levels

Forests are critically influenced by climate (Kirschbaum, 2000). Growth of forest plants depends on photosynthesis which requires several climate dependent resources like light water and atmospheric CO_2. Changes in the availability in either one of them will affect photosynthetic rates. Ceulemans *et al.* (1994), found that doubling of the CO_2 levels will generally increase plants growth to 30-60% by its effect on carbon assimilation and water loss through transpiration. This has also been supported by the results of several authors (Ceulemans and Mousseau, 1994; Curtis and Wang, 1998 and Poorter, 1993). The work of Clark,(2007) indicates that seed production of loblolly pine (*Pinustaeda)* was strongly increased by CO_2 enrichment. Elevated CO_2 level stimulates leaf -level photosynthesis which can (but may not necessarily) translate into faster growth (Korner, 2006). The stimulation of growth or net primary production in matured forests in

elevated CO_2 levels is often transient but may still be important if compounded over time (Ward and Strain, 1999).

2.6 THE BBCH SCALE

The abbreviation BBCH derives from **B**iologische **B**undesanstalt, and **CH**emical Industry is the result of teamwork between five German Research Institute. Hess *et al.* (1997), describes the extended BBCH code as a system for uniform coding of phenologically similar growth stages of all mono and dicotyledonous plant species. The use of the extended BBCH scale system is based on a model developed by Zadock *et al.* (1974), for coding the vegetative and reproductive growth in cereals.

The basic principle of the BBCH scale is to gain comparable phenological data that is necessary to define the exact plant pheno- phases which are to be observed.

Under this coding system, the entire developmental cycle of the plant is divided into ten clearly recognizable and distinguishable longer lasting phenological development phases. These include; (0) germination/bud development, (1) leaf development, (2) formation of side shoot/tillering, (3) shoot development, (4) development of harvestable /vegetative propagated parts, (5)inflorescence emergence/main shoot heading, (6)flowering, (7) fruit development, (8) ripening/fruit and seed maturity, and (9)senescence/seed dormancy as arranged by Meier, (1997). However the main phenological stages emphasized in tropical forest phenology according to Leith, (1974) include: (0) germination bud development (1) leaf flushing (6) flowering, (7) fruiting, (8) ripening/ fruit or seed maturity and (9) senescence/seed dormancy

It is clear that the principal growth stages are not sufficient enough to define exact evaluation dates since they always describe time spans in the course of the development of the plant, therefore secondary growth stages are introduced to define exact points of time or instances in the plants' development (Bruns *et al.,* 2003).

2.6.1 Principal Growth Stages on the BBCH Scale

According to Meier, (1997) the principal growth stages are described using numbers from 0 to 9 in an ascending order. These numbers do not need to proceed in ascending order but can proceed in parallel for example the flowering stage BBCH6 can occur before leaf development BBCH1 as it is in the case of some forest trees or owing to the very different plant species certain stages may even be omitted (Koch *et al.,* 2004).

2.6.2 Secondary Growth Stages on the BBCH Scale

Secondary growth stages are introduced to define exact point of time or steps in the plants development. They describe short developmental steps characteristic of the plant species that are passed successively during the respective principal growth stage. They are also coded with digits 0 to 9. The numbers 0 to 9 correspond to ordinal numbers or percentage values, 0 depicts the beginning and 9 depict the end of the principal growth stage(for example BBCH60 beginning of flowering, BBCH69 end of flowering).

2.7 SEED DORMANCY

Dormancy has been widely studied. Many hypotheses have been proposed but the regulatory principles behind changes in dormancy and induction of dormancy are still unsolved. Abscisic acid (ABA) and gibberellins (GA_S) are the hormones proposed to control primary dormancy (the type of dormancy that is acquired through seed

development). ABA inhibits, whereas GA_S induces germination (Iglesias and Babiano, 1997). Two well-known ways to overcome dormancy and promote germinations is the exogenous application of gibberellins and cold stratification or moist chilling (Bewley and Black, 1978; Baskin and Baskin, 1998). Gibberellins such as GA_1, GA_3 GA_4 and GA_7 are plant hormones that promote the germination of seeds of many species of both angiosperms and gymnosperms (Kucera *et al.,* 2005),

Seeds can be divided into the following three categories on the basis of storage behavior; orthodox, recalcitrant and intermediate (Roberts 1973; Ellis *et al*., 1991). Orthodox seeds generally have low moisture content (MC) following dispersal and can be dried to 5% or lower and stored at sub-zero temperatures (optimum ≈ -18^{o}C) for long periods of time without a loss of viability, whereas recalcitrant seeds are shed at high MC and loose viability if they are dried to a MC of less than approximately 2030%. Further they cannot be stored at temperatures below 0^{o}C. Seeds with intermediate storage behavior survive a moisture content of 6-12% and can be stored at cool (>0^{o}C) temperatures, however subzero temperatures reduce the viability of these seeds.

2.7 GERMINATION MEDIA (SUBSTRATE)

For seed germination testing, filter papers, blotters, agar, sand or soil are recommended (AOSA, 1992). Each germination medium has its own property and suitability for different species (Smith *et al.,* 2002). Soil and compost have serious deficiencies from the point of view of the seed tester. Their composition is subject to considerable variation and this affects their moisture retention capacity. They may also contain pathogens which can reduce the germination of seeds tested (Ellis *et al*., 1991). Sand is too bulky but, if prepared well it can be a satisfactory germination substrate but the laboratory must be designed and equipped to handle it. If seeds have been chemically

treated in some way (e.g. by fungicide or insecticides), testing in sand, agar or on paper can result in abnormal germination (stunted growth is a particularly common symptom). In this case it may be necessary to test on compost where such effects are minimized.

Sand is probably the most suitable medium for tropical tree seed germination due to its availability, low cost, capacity to hold moisture and suitability for large seeds (Smith *et al* 2002). For this reason and others, sand is the standard germination medium used for germination test of all species in National tree seed programme in countries such as Thailand Tanzania and Burkina Faso (Msanga, 1998). Paper is the most widely used of all substrates. Seeds are either tested on top of paper or between sheets of paper. Three types of paper are used: blotting paper, filter paper, and paper towels usually in the form of sheets or discs. The paper should be porous (to enable water to be held), but strong (to maintain structure when wet), free of fungi and bacteria, and should not contain any toxic substances which would injure germinating seedlings (Ellis *et al.*, 1991).

2.8 TEMPERATURE AND GERMINATION OF SEEDS

Temperature influences both the percentage of germination and rate of germination of seeds, and it is one of the most critical factors affecting seed germination (Smith *et al*., 2002). Seeds of each species have optimal temperatures for attaining maximum germination; most species however can reach their maximum germination at an alternating temperature regime of an 8-hour light at 30°C and 16-hour darkness at 20°C (AOSA, 1992).

2.9 DORMANCY BREAKING PRE- SOWING TREATMENT

The most common cause of delay in seed germination is the blocking of water entry into the seed coat (Cavanagh, 1980). For germination to start the impermeable seed coat must be rendered permeable. Hence pre sowing treatment of most tree seeds is deemed necessary and most species need definite treatment for breaking seed dormancy (Nalawadi *et al;* 1977, Ramorthy *et al.*, 2005). Various techniques such as chemical and mechanical scarification, hot and cold water treatment have been devised to break dormancy in forest tree seeds with the view of improving germination.

2.10. SPECIES INFORMATION

2.10.1 *Terminalia superba*

It belongs to the family Combretaceae (Irvine, 1961). It is a tropical pioneer tree common in upland and semi- deciduous forests across West Africa (Guinea to Cameroon). It is usually a long, straight, slender tree with height ranging from 10-50m (Hawthorne and Gyakari, 2006). Its fruit is two- winged and bears a single seed. The germination capacity of the seeds, however, is drastically reduced a few months after harvesting under ambient or room temperature (Gyimah, 1984). According to Schaeffer (1990), seeds of tropical genus *Terminalia* are identified as short-lived and recalcitrant and that both chemical and physical seed coat dormancy has been recognized as well. The FAO (1998), reports that seeds of the species do not store well under ambient temperature or at high moisture level. Seeds of good initial quality can be stored satisfactorily at a temperature of 4°C, provided a low humidity can be maintained (airtight containers, room with controlled humidity).

2.10.2 *Terminalia ivorensis*

This tree is also a Combretaceae (Irvine, 1961). It is a pioneer tree, common in upland and semi-deciduous forests of Guinea to Cameroon. The species is used as building poles, roofing shingles and for medicinal purposes (Irvine, 1961). Somade (1985) described the seed storage behaviour of *Terminalia ivorensis* as orthodox. The seeds of *Terminalia ivorensis* germinate with difficulty and its inability to germinate is probably due to seed coat dormancy because this is thick and lignified (Corbineau and Côme, 1994).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY SITE

The Bobiri forest is a natural forest reserve close to the city of Kumasi, capital of Ashanti region in Ghana. It is located 35km southeast of the regional capital and 2.5km off the main Kumasi-Accra road at the village of Kubease (Fig 3.1). It lies on latitude 06^0 40'N to $6^0$44'N and longitude $01^0$15'W to $01^0$22'W. It is a forest reserve covering an area of 5504.00ha (55.04km^2) surrounded by six forest host communities. The area also serves

as a research site for the Council for Scientific and Industrial Research-Forestry Research Institute of Ghana (CSIR-FORIG). It is a biodiversity conservation site home to many plants and animal species.

The site falls within the moist semi-deciduous forest ecological zone which is the most extensive closed canopy forest type in Ghana. This type or quite similar types are abundant throughout West Africa. Trees tend to be 50-60m and are the tallest of any forest type. Deciduous and evergreen species are represented in about equal proportion often with several canopy layers (Hall and Swaine, 1981).

The climate has a peak rainfall period in June- July, September-October and a marked dry season in November through March. Prevailing wind is south to south westerly but during the dry season the Harmattan blows from the north east. Geological survey shows the locality as being on the Cape Coast granite series.

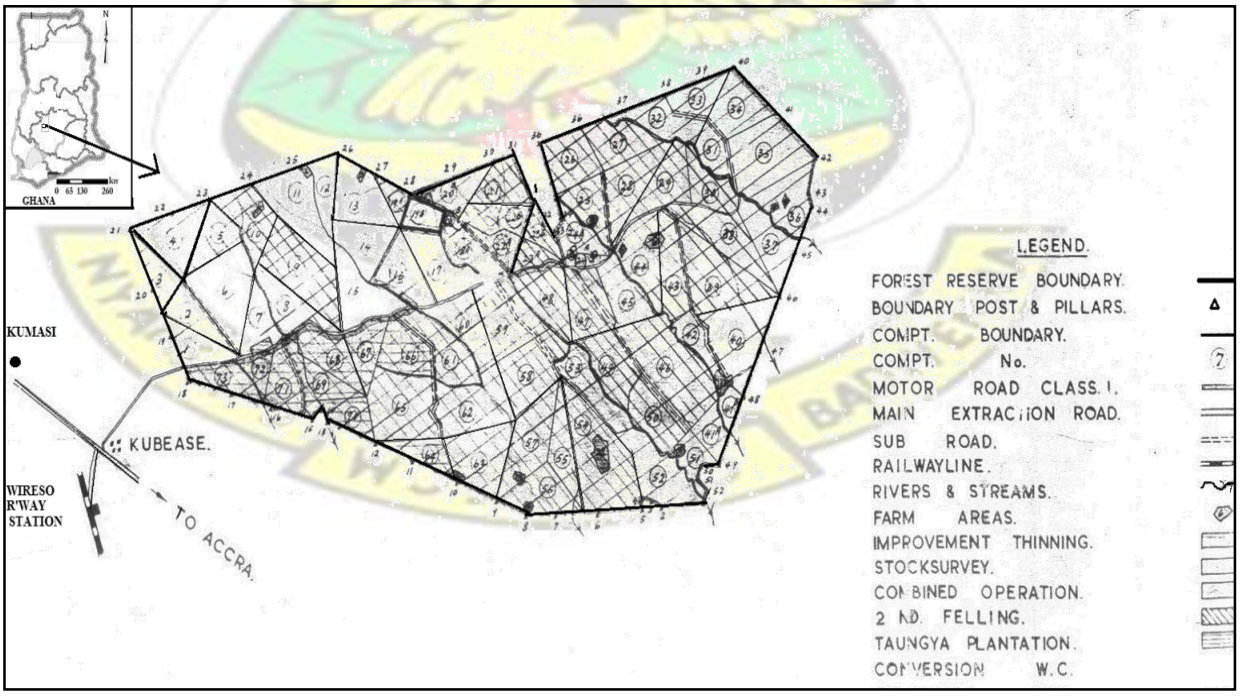

Figure 3.1: Map of the Bobiri forest reserve indicating the various compartments.

3.2 PHENOLOGICAL SURVEY

A total of one hundred and fifteen (115) matured individual stands of *T. superba* and *T. ivorensis* were tagged with labels and their positions recoded with GPS to facilitate relocation. The sampled trees were monitored from January 2013 to December 2014 at a two weekly interval. Individual trees were selected along the phenological route if they appeared to be healthy, had a crown easily observed from the trails and were of reproductively matured size of at least 20cm DBH (Diameter at Breast Height; 1.4m above ground).They were scanned with binoculars, digital cameras as well as visual assessment of the crown with the assistance of Tree climbers (Figure 3.2). The various phenological phases were scored using the BBCH system of scoring tree phenology (Borchet *et. al.* 2005; and Schwartz, 2003).

For each tagged tree, records were made on its periods of leaf development, leaf fall, flowering, fruiting and seed dispersion (Shukla *et. al.*, 2005). Because no observations were made during the interval between two sampling dates (approximately 15 days), it was assumed that in a tree, a particular pheno-phase began before or continued beyond the date of first/last record by one half sampling interval following the protocol adopted by Singh and Kushwaha, (2006). A species was considered to be passing through the peak of a pheno-phase when more than 50% of the individuals of that species did so (Shukla *et al.*, 2005).

The single most useful characterization of the timing of dispersal was the date preceding the largest decrease in the fruit rating. This could resolve the methodological problem of distinguishing dispersal from loss due to abortion predation, and physical damage.

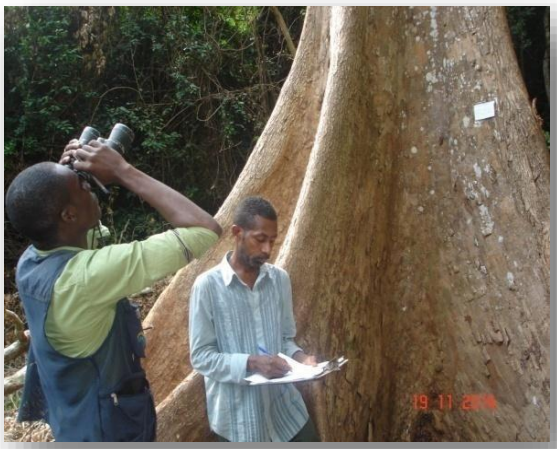

Plate 3.1 Ground phenological assessment of study species using binoculars (Panel A). Climbing for crown phenological assessment of phenology in *T. ivorensis* (Panel B*)*

Monthly climatic data on rainfall and temperature within the ecological zone of the study site were obtained from the nearest computerized meteorological station located on the compound of the CSIR- Forestry Research Institute of Ghana (FORIG).

3.3 COLLECTION AND PROCESSING OF SEED SAMPLES

Seeds of the species were collected within the research working cycle of the Bobiri Forest reserve between Septembers to December 2014. Seeds were spread on wheat sacks and cleaned of twigs, bark, foliage and other impurities (Turnbull, 1975). They were then shade-dried for 3 days, packed into cotton bags and transported to the Seed Laboratory of the National Tree Seed Center at CSIR-Forestry Research Institute of Ghana where germination studies were to be conducted.

Seed samples of *Terminalia superba* Seed sample of *Terminalia ivorensis*

Plate 3.2 Pictures of the two seed samples. *Terminalia superba* (Panel A), *Terminalia ivorenisis* (Panel B)

3.4. CHEMICAL AND MECHANICAL SCARIFICATION TREATMENTS

All seeds to undergo the various germination treatments were surface sterilized by soaking in 5% sodium hypochlorite (NaHOCl) solution for 10 minutes and subsequently rinsed thoroughly with sterilized water. The seeds were subjected to four different treatments (mechanical and chemical scarification) namely;

- Seeds manually scarified by piercing seed coat with needles at the cotyledon end (T1)
- Soaking seeds for 10 min in Potassium Nitrate (KNO_3) (2g/ l) prior to germination (T2)
- Soaking seeds for 10 min in Sulphuric acid (H_2SO_4) of 2M concentration prior to germination (T3)
- Dewinging of seeds prior to sowing (T4)
- A control experiment was set up using untreated seeds of both seed species.

3.5 SEED GERMINATION TRIALS

Thirty (30) seeds were tried in each four treatments. Treated seeds were sown in 15cm plastic Petri-dishes in three replicates with 10 seeds for each replication (Young and

Young, 1992). Seeds were incubated on a gel of 1% water-agar substrate at 30^0C. Germination was recorded at two day intervals and seeds were counted as germinated when radicle and plumule attained at least 1cm and free from visual fungal infection or deformation (Rawat, 2005). Germinated seeds were discarded from the Petri dishes on each count. Final germination was calculated as the maximum germination obtained when no further germination took place for several days.

3.6 CALCULATION OF MEAN GERMINATION TIME, AND SPEED OF GERMINATION

As a measure of germination kinetics, the mean germination time (MGT), a measure the spread of germination of seeds was calculated according to Tompset and Pritchard (1998) formula:

- $$MGT\ (t) = \frac{\Sigma ni.ti\ (days)}{\Sigma n}$$

Where,

t = mean germination time in days

ni = number of germinated seeds during a given time interval

n = total number of germinated seeds.

- Speed of germination was derived by taking the germination count at weekly interval up to 36 days and computed according to the method proposed by Maguire (1962).

3.7 STATISTICAL ANALYSIS

3.7.1 Phenological Survey

The duration of a phenological event in the species was computed by obtaining the number of days required for the completion of an event from the first observation date

of that event following the methods prescribed by author (Opler *et al.*, 1976). Image J computer software was used in transforming digital images of tree crowns taken into nominal percentages. A correlation analysis was carried out between the mean dates of phenological events and weather data variables (temperature, rainfall) following the methods of (Polte- Rudolf, 1993).

3.7.2 Germination Studies

A completely randomized block design (CRBD) was adopted for the germination studies. Analysis of variance (ANOVA) was used to determine significance in the data obtained using the Genstat statistical package. Mean separation was done after the ANOVA using standard error of the difference (s. e .d).

CHAPTER FOUR

4.0 RESULTS

4.1 FLOWERING AND FRUITING PHENOLOGY

4.1.1 *Terminalia superba*

Flowering phenophase in *T. superba* started in mid-June for both years with 15% and 21% of individuals under observation initiating flowering for Year 1 (Y1) and Year 2 (Y2) respectively (Figure 4.1). Months of flowering initiation recorded the highest mean monthly rainfall for both years with 35.4mm for Y1 and 33.2mm for Y2. Flowering season covers the months of June through October with a slight extension to mid-November for Y2 (Figure 4.2). Peak flowering in the species occurred in the months of October (83% and 85% for Y1 and Y2 respectively). Very low flowering (3%) was observed in December of Y2 with no flowering recorded in the first year when mean monthly rainfall were lowest (3.3mm and 4.2mm for Y1 and Y2 respectively). The period between January- May had no recorded case of flowering for the species.

Table 4.1 Summary of fruiting and flowering pheno-phases of the study species

Year	Species	Phenophase	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st	*T.superba*	Flowering (%)	-	-	-	-	-	15	28	33	47	83	33	-
		Fruiting (%)	79	31	-	-	-	-	-	-	-	23	46	58
	T.ivorensis	Flowering (%)	-	-	-	-	26	31	44	83	23	-	-	-
		Fruiting (%)	-	-	-	-	-	-	-	25	44	63	69	23
2nd	*T.superba*	Flowering (%)	-	-	-	-	-	21	34	43	50	85	77	3
		Fruiting (%)	83	-	-	-	-	-	-	-	-	33	42	51
	T.ivorensis	Flowering (%)	-	-	-	-	18	23	38	75	62	43	-	-
		Fruiting (%)	-	-	-	-	-	-	-	-	13	34	75	66

Fruiting duration in *T. superba* is approximately 4-5 months spanning October - February. Slight overlap of about 18 days was recorded in flowering and fruiting phenophases for the months of October and November in both years. Peak fruiting (79% and 83% for Y1 and Y2) occurred in January when mean monthly maximum temperatures were highest (31.8^0C and 32.1^0C for Y1 and Y2 respectively) compared with the rest of the months (Fig 4.2&4.3). Fruiting pheno-phases in the species were preceded by intense seed dispersal during the dry months of November- February.

4.1.2 *Terminalia ivorensis*

Flowering phenol-phase in *T. ivorensis* began in May for both years with 26% and 18% of individuals under observation initiating flowering in Year 1 (Y1) and Year 2 (Y2) respectively (Figures 4.1, 4.2). Flowering in the species coincided with the onset of the wet season in May after the extended dry season. The longest fruiting season of approximately 6 months (May-October) was observed in T. *ivorensis* for Y2. Peak flowering (83% for Y1 and 73% for Y2) occurred in August for both years. There was no significant recorded flowering activity in the study species during the dry months of November-March. Fruit setting closely following the abscission of flowers in October in this species and lasted for approximately 3 months (October-December). Fruit setting in the first year seems to have begun about a month earlier (late August) than in the second year which began in October. Peak fruiting (69% and 75%) occurred in November when mean monthly maximum temperatures were relatively high (30.6^0C and 31.6^0C).

Leaf fall in general for both species was higher from November-February coinciding with the dry-cool season. During this period there were recorded cases of certain individuals attaining complete leaflessness.

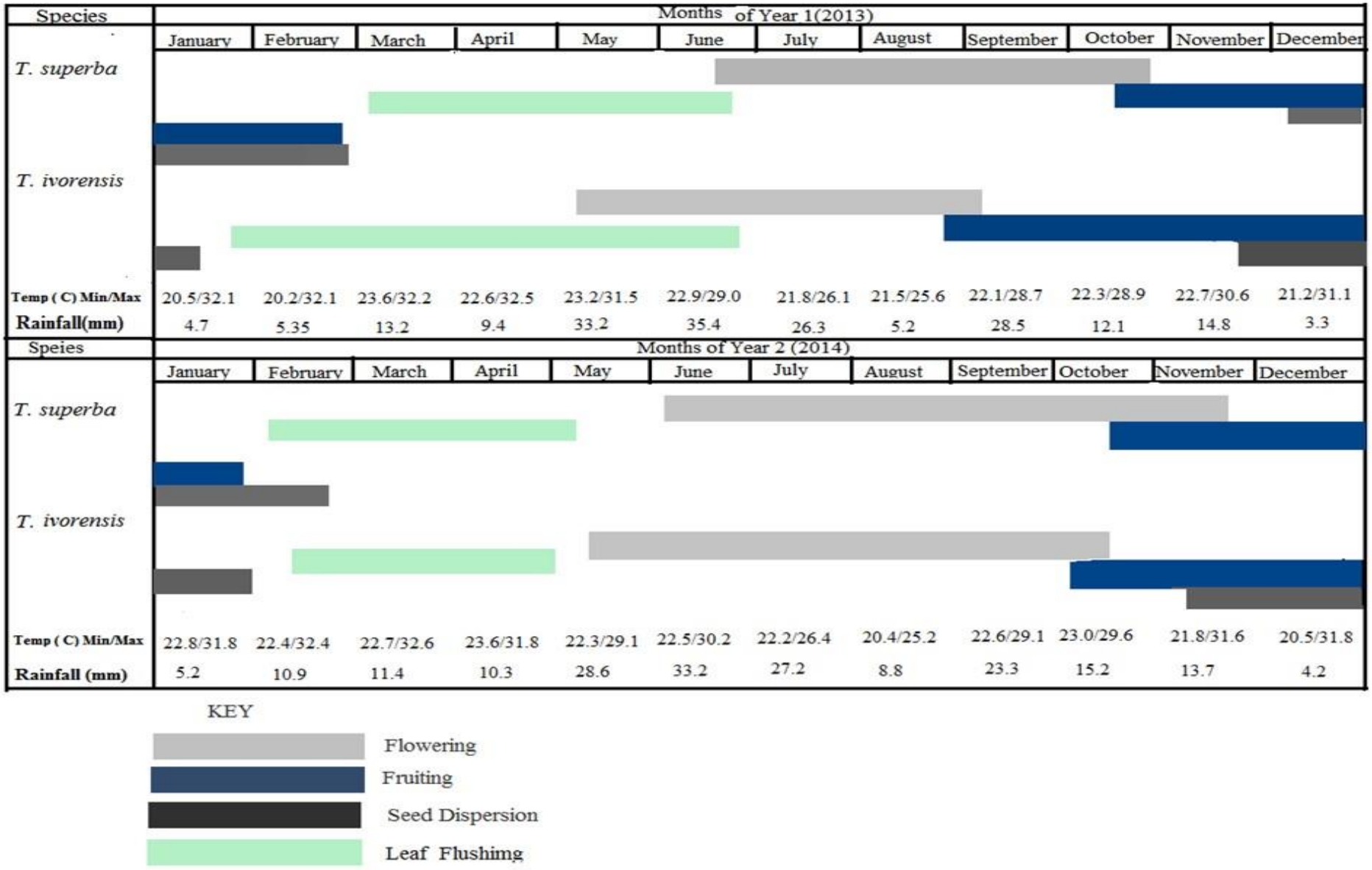

Figure 4.1 Phenochart of the species based on a two year reproductive cycl**e**

Plate 4.1 Fruiting pheno-phase in *T superba* as observed in October 2014

4.2 LEAF FLUSHING AND FRUITING

Leaf flushing in the two species generally occurred in the three months of March, April and May throughout the study period. Unlike leaf flushing in *T. superba*, *T. ivorensis* began flushing new leaves earlier in the year in February where 57% of observed stands were flushing pheno-phase. The longest period of leaf flushing in the species was recorded in *T. ivorensis* in the first year which began in late January and ended in June with a peak flushing occurring in May (Plate 4.1).

Seed dispersion phenology in both species showed a similar pattern. Seed dispersion was observed in the cool dry months of November through February for both species. The peak period of seed dispersion was recorded in mid to late December, where 75% and 83% of *T. ivorensis and T. superba* respectively dispersed seeds. Seed dispersion occurred alongside leaf fall in the dry cool season when most deciduous species within the ecological zone were shedding leaves.

4.3 METEOROLOGICAL DATA

The climate at the study site is bi - modal characterized by two wet seasons (April-June and September- October) and two dry seasons (a minor dry season from July-August and a major dry season from November – March). Precipitation was low in December-March.

Maximum temperatures were higher from November-March than during the rest of the year. December and January were the months with the highest maximum temperatures, least precipitation and thus less cloud cover resulting in a dry-cool season (Figure 4.2).

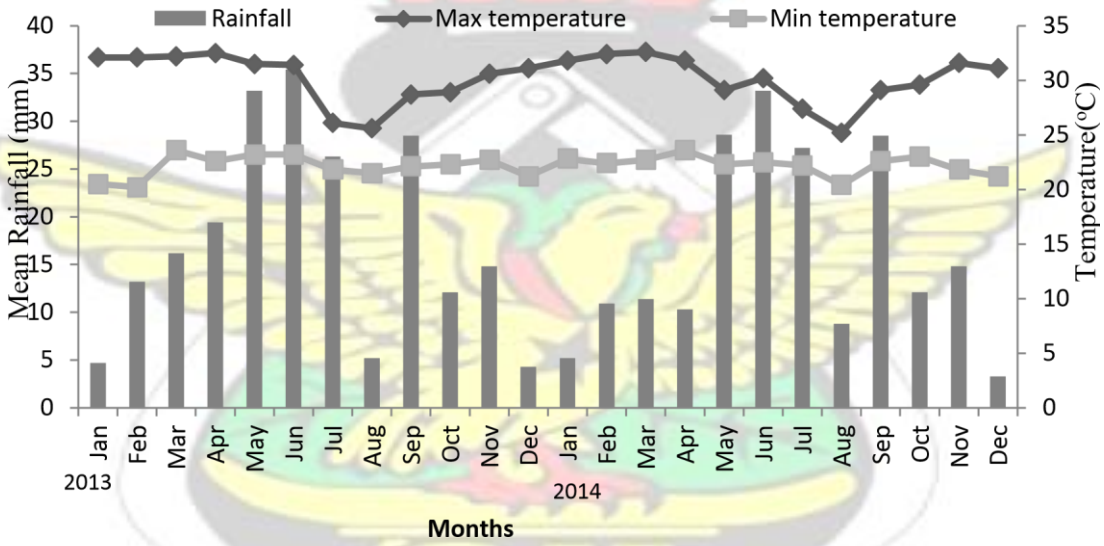

Figure 4.2: An Ombrothermic diagram of the study site from Jan 2013-Dec 2014

4.4 PHENOLOGY- CLIMATE VARIABLES CORRELATION

Pearson Correlation analysis carried out between the nominal percentage values (intensity) of the various reproductive pheno-phases, and corresponding monthly mean values of temperature and rainfall is shown in Table 4.1. Both species indicated a strong positive correlation between rainfall (RA) and leaf flushing (LF) based on the criteria by Evans,(1996). Correlation coefficient r = 0.732 and 0.6814 for Y1 and Y 2

respectively were recorded in *T. superba* at P> 0.05. Similarly, *T. ivorensis* gave coefficients of 0.6916 and 0.7321 respectively for the study duration at the same level of significance (P >0.05). Seed dispersion intensity (SD) showed a moderate positive correlation with mean maximum temperature (TE^{mx}) during months of dispersion for both species (Table .4.2).

Table 4.2 Pearson correlation between monthly weather conditions (air temperature and rainfall) with reproductive phenological phases (p < 0.05)

Correlations	*Terminalia superba*		*Terminalia ivorensis*	
	Year 1	Year 2	Year 1	Year 2
RA vs. FL	-0.2724	-0.2516	-0.1372	-0.1831
TE vs. FL	0.1942	0.1873	0.014	0.025
RA vs. FR	-0.5702	-0.4921	-0.2142	-0.0296
TE vs. FR	0.0238	0.0423	0.0328	0.0253
RA vs. LF	0.735	0.6814	0.6916	0.7321
TE vs. LF	-0.6251	-0.5712	-0.2691	- 0.3117
RA vs. SD	0.0172	0.0143	0.0958	0.04521
TE vs. SD	0.8213	0.8576	0.7547	0.6261

RA – Mean Monthly Rainfall
TE– Mean Monthly Temperature
FL – Flowering Intensity
FR– Fruiting Intensity
LF – Leaf flushing
SD – Seed Dispersion Intensity

4.5 SEED DIMENSIONS

Seed dimensions and seed weights of both species based on 50 individuals measured are presented in Table 4.2. The data are mean values (±SD).

Table 4.3 Seed dimensions and Seed weight of species based on 50 individuals. The data are mean values (±SD)

Dimensions	***Terminalia superba***	***Terminalia ivorensis***
Length (mm)	20.3 ± 2.7	22.1 ± 1.8
Breadth (mm)	6.6 ± 0.9	9.5 ± 0.5
Width (mm)	5.6 ± 0.5	5.8 ± 0.6
Weight/Seed (g)	0.12 ± .002	0.16 ± .002

Terminalia superba: The mean seed length, breadth and width recorded for *T. superba* were 20.3 ± 2.7, 6.6 ± 0.9 and 5.6 ± 0.5 mm, respectively. The mean seed weight obtained for *T. superba* was 0.12 ± 0.02 g.

Terminalia ivorensis: The mean seed length, breadth and width recorded were 22. ±1.8mm, 9.5 ±0.8mm and5.8±0.6mm respectively. The mean seed weight obtained for *T. ivorensis* was 0.16 ± 0.02 g.

4.6 SEED GERMINATION TRIALS.

Results of germination improvement trials are presented in Table 4.4 and 4.5 for *T. superba* and *T. ivorensis* respectively. With the exception of the control (untreated), germination of seeds manually scarified by nicking seed coat (T1) showed the least germination percentage (54%) and the longest mean germination time (MGT) of 19 days. A significantly high germination (84%) however was observed in treatment 3 where seeds soaked in H_2SO_4 2g/l for 20 minutes prior to sowing. This treatment resulted in the fasted germination of 9 days and a germination percentage of 73%. In general, dewing seeds increased germination from 32% (control) to 73% and reduced MGT from 17 days to 14 days.

Table 4.4 Germination trials of *Terminalia superba* for a period of 36 days.

Seed Treatments	1st Germination (Days)	MGT* (Days)	Germination (%)	Observation
Scarified seeds(nicking)	13	19	54	Normal seedling
KNO_3 treated seeds	10	18	64	20% abnormal
H_2SO_4 treated seeds	9	16	84	Normal Seedlings
Dewinged seeds	14	14	73	Normal seedling
Control	11	17	32	Normal seedlings
SED	1.08	1.42	2.5	
CV	3.2%	2.4%	4.2%	

*MGT is mean germination time in days

None of the seeds of *T. ivorensis* manually scarified by nipping showed any sign of germination. Germination in the species was observed to be low in all treatments compared with *T superba*. The highest germination percentage (37%) was observed in the treatment 3 (soaking seeds in H_2SO_4 for 20 minutes prior to sowing) with MGT of 23 days. Chemical treatment by KNO3 2g/l could not improve germination but rather reduced germination from 20% (control) to 16 %.

Table 4.5 Germination trials of *T. ivorensis* for a period of 36 days.

Seed Treatmenst	1st Germination (Days)	MGT* (Days)	Germination (%)	Observation
Scarified seeds(nicking)	-	-	-	No germination
KNO_3 treated seeds	18	29	16	Normal seedlings
H_2SO_4 treated seeds	14	23	37	Normal Seedlings
T Dewinged seeds	13	20	23	30% abnormal
Control	19	25	20	Normal seedlings
S.E.D	2.14	2.06	1.68	
C.V	2.6%	3.4%	3.8%	

*MGT is mean germination time in days

CHAPTER FIVE

5.0 DISCUSION

5.1 LEAF FLUSHING AND FLOWERING PHENOLOGY

Recent studies have indicated that seasonal peaks and depressions for leaf flush, leaf fall flowering, and fruiting are quite common in tropical rainforest with pronounced dry periods (Forest and Miller 2010; Sonnentag *et al.*, 2012,). The flowering, fruiting, and leaf-flushing pheno-phases of the tree stands examined in this study demonstrated a significant 12-month periodicity in their reproductive cycles.

Phenological observations in the studies for both species of *Terminalia superba and Terminalia ivorensis* revealed that leaf flush was triggered at the onset of the rains from February–June after a spell of the dry cool season (Figure 4.2). Emergence of leaves peaked in the months of May and June when rainfall intensity was highest in both years (33.2mm and 35.4mm for Year1; 28.6mm 33.2mm for Year 2).The results revealed a strong positive correlation between Rainfall (RA) and Leaf flush (LF) with a correlation coefficient as high as r = 0.735 (Table 4.1). Similar results have been reported by authors Kikim *et al.,* (2001) and Morellato (2000).

That leaf flush and flowering occurred mostly in the wet seasons and virtually absent in the dry cool months of November through March for both species is in accordance with the findings of Dean *et al*. (2005), who worked on tree species in a similar ecological zone in Ivory Coast. The response of the species to rains indicated their phenology was largely driven by water availability than photoperiod. Simultaneous flushing and flowering of both species at the onset of the rains in May indicated an intensive use of stored resources.

Van Schaick *et al.* (1993), explains that in moist semi- deciduous tropical forests, community wide leaf flushing peaks tend to occur during the time of the year with high temperatures, rainfall and longer hours of sunshine. This enables forest tree species to use the favorable rainy season for leafing in order to accumulate sufficient photosynthate and initiate reproduction prior to the steep fall in soil water reserve during the drier periods in the annual cycle.

Flowering period in *T. superba* seems to have been extended to mid-November in Year 2 overlapping with its fruiting phenol-phase in that month at the onset of the dry season with high average temperatures of 31.6^{o}C (Fig 4.2). This phenomenon observed in other tropical tree species is believed to aid in the attraction of insect pollinators since their activity is greatest in the months with warm and dry days (Augspurger, 1982). Bhat (1992) believes that an advantage of dry season flowering is to enhance visibility of flowers to pollinators since the tree may be lacking leaves.

Peaks in leaf fall coincided with intense dry season with high average maximum and minimum temperatures of 21.2^{o}C/31.1^{o}C and 20.5^{o}C/31.8^{o}C for Year 1 and Year 2 respectively. The period of complete leaflessness was observed in some individuals during the drier months of December through February for both study species. This leafless period is an adaptation to avoid water stress which affects flowering time in tropical forest trees (Bullock, 1995). Increase in leafless period in deciduous species also causes a reduction in vegetative growth to avoid water loss through excessive evapotranspiration. There are several reports of maximum leaf fall during the driest part of the year in different tropical forest types (Frankie *et al.,* 1974; Borchert *et al.,* 2000).

5.2 FRUITING AND SEED DISPERSAL PHENOLOGY

Fruiting phenology is partially, but not entirely contingent on the flowering phenology. The time interval between pollination and fruit maturation varies between species (Chapman *et al.* 2004), and several biotic and abiotic factors may inhibit fruit maturation. The longest fruiting phenol-phase in *T. superba* occurred over a period of four to five months (October-February). Peak fruiting in the species was observed in October in each of the years. Fruiting and flowering pheno-phases in the species slightly overlaped in October for Year 1.*T. ivorensis* on the other hand revealed three months of intense fruiting pheno-phase (October -December) with peak fruiting in November in each year. It was also observed that fruiting period in the species started earlier with a longer duration of fruiting season in that year (August- December). Longer duration of fruiting implies the availability of fruits and seeds to frugivores and seed predators for a longer period of time as suggested by Herms (2004). Peak fruiting in both species occurred in periods of relatively higher average monthly precipitation of 14.8mm and 13.7mm respectively for Year 1 and Year 2 (Figure 4.1).The need for high moisture levels and rainfall for the proper development of fleshy fruits in most forest tree species has been reported by Zahner, (1968) who showed experimentally that the shortage of soil moisture reduced the rate of enlargement and final size of forest tree fruits. Fruits produced during the dry season, were mostly dry. Results from the study indicated a poor correlation between fruiting pheno-phase and average minimum and maximum temperatures (FR vs TE on Table 4.1). The reason accounting for this poor correlation is that, factors other than temperature, such as shortened photoperiod (Delpierre *et al.* 2009;Vitasse *et al.*2011), age and soil water availability (Archetti *et al,* 2013) may regulate the timing of the fruiting pheno-phase in both species.

Seed dispersal pheno-phase in both species occurred in the cool dry months of December-February. Dispersion of seeds was strongly correlated (r = 0.8213, 0.8576 and r= 0.7547, 0.6162 for *T. superba* and *T. ivorensis* respectively) with average

maximum temperatures. This trend has been reported by authors such as Clark, (2007) and Colwell *et al.,* (2008).

5.3 DORMANCY BREAKING PRE- TREATMENTS

5.3.1 *Terminalia superba*

Analysis of results indicated that there was significant difference at P≤ 0.05 with standard mean error of ±1.68 among the different germination treatments in *T. superba* seeds. Comparisons of the various treatments revealed that, highest germination percentage (84%) in *T. superba* seeds was observed in seeds treated with H_2SO_4 (Table 4.5). Treatment of *T. superba* seeds by soaking in H_2SO_4 2g/L for 20 minutes before sowing resulted in the highest germination with 1st germination occurring in 9 days. The earlier and higher germination of seeds soaked in H_2SO_4 may be due to the fact that seed coat biochemical interactions with the acid enhance heat promotion for better scarification. This interaction gave the seeds an added advantage of early rehydration, leaching of inhibitors and initiation of metabolic processes and growth (Copeland and McDonald, 1995).The results agree with the work of Nalawadi *et al*. (1977), who demonstrated experimentally that tree seeds soaked in concentrated H_2SO_4 for 5 - 20 min and then soaked in water for 24 h observed good germination compared with the seeds soaked in water alone. Immersion in concentrated sulphuric acid has been successfully used as a means of scarifying impermeable seeds (Teem *et al.*, 1980). Seeds used in the control trials (untreated) resulted in the lowest germination percentage of 32% compared with all other treatments, indicating the fact that *T. superba* seeds require pre sowing treatments for good germination. Similar results have been reported by Ramoothy *et al.* (2005), who investigated the effect of pre sowing treatment on *Terminalia catappa.*

5.3.2 *Terminalia ivorensis*

The highest germination percentage (37%) in *T. ivorensis* was also observed in H_2SO_4, treated seeds followed by seeds treated in dewinging. It was observed that very low germination (4%) was recorded for in the manual scarification of seedcoat by nicking. *T. ivorensis* seeds have a very hard seed coat which makes imbibition difficult. Nicking and complete removal of the seed coat should have had a marked positive effect on germination. However, the small size of the seed and the hard seedcoat often resulted in embryos being damaged during pre-treatment resulting in low germination for seeds treated by nicking (Msanga and Maghembe, 1989).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

From the present study conducted on the phenology and seeds germination of two important forest trees in the moist semi deciduous forest zone of Ghana namely,

Terminalia superba and *Terminalia ivorensis* the following conclusions and recommendations could be made:

- *Terminalia superba* and *Terminalia ivorensis* both undergo a consistent and synchronized annual reproductive phenological cycle within the moist semi-deciduous forest zone of Ghana.
- Leaf flushing in *Terminalia superba* and *Terminalia ivorensis* coincides with the onset of the raining season in April-July, and it is followed by flowering in August-September within the ecological zone. Fruiting and seed dispersalpheno-phases occur for approximately 5 months in the year (OctoberFebruary).
- Dispersal of matured seeds in both species is usually in the dry-cool season of November- January when average monthly minimum and maximum temperatures are highest in the year.
- For better germination, both the seeds of *Terminalia superba* and *Terminalia ivorensis* require some form of pre sowing treatment. The best treatment to enhance seed germination is soaking in H_2SO_4 for at least 20 minutes prior to sowing.

6.2 RECOMMENDATIONS

- Optimum seasons for wild collection of the seed of both *Terminalia superba* and *Terminalia ivorensis* in the ecological zone for germination and *ex situ* conservation programmes must be in the cool dry months of the year with average minimum and maximum temperatures close to 20.5ºC/31.8ºC.

Phenochart of the species developed out the results of this study will be submitted to the National Tree Seed Center in Ghana for review and adoption.

- Advanced technique of monitoring forest phenology such as the Normalized Different Vegetation Index (NDVI) for a detailed monitoring of phenology should be adopted for several species within the zone.
- The effect of varying temperature regimes and chemical concentrations could be investigated.

REFERENCES

Aide T. M. (1992) Dry season leaf production: an escape from herbivory. *Biotropica* **24**:532–537

Archetti M, Richardson A.D., O'Keefe J, Delpierre N. (2013). Predicting climate change impacts on the amount and duration of autumn colors in a New England forest. One 8: 1–8, doi: 10.1371/journal.pone.0057373.

Aronson J, L., Kigel J., Shmida A., Klein J. (1992). Adaptive phenology of desert and mediterranean populations of annual plants grown with and without waterstress.*Oecologia* **89**, 17–26.

Association of Official Seed Analysts (AOSA) (1992). Rules for Testing Seeds.*Journal of Seed Technology*.**6**: 1 – 125.

Augspurger C. K. (1982). Reproductive synchrony of a tropical shrub: experimental studies on effects of pollinator and seed predators on *Hybanthusprunifolius* (Vioraceae). *Ecology* **62**:775–788

Badeck F.W., Bondeau A., Bottcher K. P., , Lucht W, Schaber J, Sitch S.(2004). Responses of spring phenology to climate change. *New Phytologist***162**, 295–309

Baskin C.C., Baskin J.M (1998). 'Seeds: ecology, biogeography, and evolution of dormancy and germination.' *International Journal of Plant Sciences***70**, 174–181.

Bawa, K., Ashton, P., SallehMohd, N., (1990). Reproductive ecology of tropical forest plants: management issues. *Man and the Biosphere Series*, **vol. 7**. P. 7-8

Bawa, K. S., and Hadley, M., (1991). Reproductive ecology of tropical forest plants. Man and the Biosphere Series, **vol.7.**UNESCO.

Bellard C, Bertels C, Leadley P, Thuiller W., Courchamp F (2012). Impacts of climate change on the future of biodiversity. *EcolLett* **15** 365–377

Beuker E. (1994). Adaptation to climatic changes of the timing of bud burst in populations of Pinussylvestris (L.) and Piceaabies (L.) .*TreePhysiology* 14: 961–970

Bewley J. D and Black M. (1978). Physiology and biochemistry of seeds,Vol. 1. *Springer:* Berlin, Heidelberg New York, **306pp**

Bhat D. M. (1992). Phenology of tree species of tropical moist forest of Uttara Kannada district, Karnataka, India . *J.Biosci.*, Vol. **17**, Number 3, September 1992, p 325-352.

Borchert R, Rivera G, Hagnauer W. (2000). Modification of vegetative phenology in a tropical semi-deciduous forest by abnormal drought and rain. *Biotropica* **34**: 27–39.

Borchert R, Robertson M. K., Schwartz M. D., Williams-Linera G. (2005). Phenology of temperate trees in tropical climates. *International Journal of Biometeorology* **50**: 57–65.

Brookman-Amissah, J. (1997). Seed problems as they affect forestry practice in Ghana.Vol.II Paper No.6.*International Union of Forest Research Organisation*. *International* symposium on seed processing, Bergin, Norway, 1973. Pp 1-9.

Bruns, E., Chmielewski, F.M., Vliet, A. v., (2003): The Global phenological monitoring concept . *J. Trop. Ecol*. **21**: 1–14.

Bullock, S. H. (1995). Plant reproduction in neotropical dry forests. n: Bullock, S.H., Mooney, H.A., Medina, E. (Eds.), Seasonally Dry Tropical Forests. *Cambridge University Press, Cambridge U.S.A,* pp. 203277.

Cavanagh A. K. (1980). A review of some aspects of the germination of acacias. Proc. R. Soc. *Victoria* **91**: 161-180.

Ceulemans, R., Mousseau, M.,(1994). Effects of elevated atmospheric CO2 on woody plants. *New Phytol*. review no. **71**, 425–446.

Chapman C. A., Struhsaker A. E., Zanne, C. J., Clark C. J. (2004). A Long-term evaluation of fruiting phenology: importance of climate change. *J. Trop. Ecol*. **21**: 1–14.

Chen, X., Xu, L.(2012). Temperature controls on the spatial pattern of tree phenology in China'stemperate zone. *Forest.Meteorol*. **154**–155, 195–202.

Christensen J.H., Hewitson B, Busuioc A, (2007). Regional climate projections. In: the physical science basis. *Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change.* Cambridge, UK; New York, USA: Cambridge University Press.

Clark D. A. (2007). Detecting tropical forests' responses to global climatic and atmospheric change: current challenges and a way forward. *Biotropica* **39**: 4–19.

Cleland E.E., Allen J.M., Crimmins T.M., Dunne J.A., Pau S, Travers S, Zavaleta E.S., Wolkovich E. M. (2012) Phenological tracking species responses to climate change. *Ecology* **93:**1765**–**1771

Cobbinah J.R. Siaw K.A. and Gyimah, A. (2001). Guide to tree planting in Ghana. Published by the*Forestry Research Institute of Ghana*. **33p**.

Corbineau, F, Cô me, D. (1986). Experiments on germination and storage of the seeds of two dipterocarps: Shorea roxburghii and Hopea odorata. Malayan Forester, 49: 371- 381.

Colwell RK, Brehm G, Cardelus C.L, Gilman AC, Longino JT. (2008). Global warming, elevation range shifts, and lowland biotic attrition in the wet tropics. *Science* **322**: 258–261.

Copeland, L.O. and M.B. McDonald.(1995). Principles of Seed Science and Technology.*Burgess Publication Company,* Minneapolis, Minnesota.

Curtis, P. A.,Wang, X., (1998). A meta-analysis of elevated CO2 effects on woody plant, mass form, and physiology. *Oecol*. Berlin **113**, 299–313.

Dean P. Anderson S., Erik. V., Nordheim, Timothy C. Moermond K., Zoro B., Gone B. (2005). Factors influencing tree phenology in Tai National Park, Cˆote d'Ivoire. *Biotropica* **37**(4): 631–640

Delpierre N, Dufrêne E, Soudani K, Ulrich E, Cecchini S, BoéJ,François C. (2009). Modellinginterannual and spatial variability ofleaf senescence for three deciduous tree species in France.*Agric. For.Meteorol.149*: 938–948.

Devineau J.L. (1999). Seasonal rhythms and phenological plasticity of savanna woody species in a fallow farming system (south- west Burkina Faso).*Journal of Tropical Ecology***15** 497-513.

Doi H, Takahashi M, Katano I. (2010). Genetic diversity increases regionalvariation in phenological dates in response to climate change. *GlobalChange Biology* 16: 373–379.

Ellis RH, Hong TD, Roberts EH (1991). An intermediate category of seed storage behaviour? Effects of provenance, immaturity and imbibition on desiccationtolerance in coffee. *Journal of Experimental Botany***42**, 653–657.

Evans, J. D. (1996). Straightforward statistics for the behavioral sciences. Pacific Grove, CA: Brooks/Cole Publishing.

FAO (2005). State of the world's forest, Rome, Italy.

FAO (1998). Forest Genetic Resource Information No. 16 (FAO), Rome.

Fitter, A. H, and Fitter S.R. (2002). Rapid changes in flowering time in British plants. *Plant Science***296**, 1689–1691.

Forest J.and Miller-Rushing A. J. (2010). Toward a synthetic understanding of the role of phenology in ecology and evolution Philosophical Transactions of the Royal Society. *Biological Sciences* **365:** 3101-3112.

FORRU (Forest Restoration Research Unit) (2006). How to plant a forest: The principles and practice of restoring tropical forests. *Biology Department, Science Faculty,* Chiang Mai University, Thailand.

Frankie, G. W., Baker, H. G. & Opler, P. A.,(1974). Comparativephenological studies of trees in tropical wet and dry forests in the lowlands of Costa Rica. *J. Ecol*. 62: 881-919.

Gazal R, White MA, Gillies R, Rodemaker E, Sparrow E, Gordon L. (2008). Globe students, teachers, and scientists demonstrate variable differences between urban and rural leaf phenology. *Global Change Biology* **14**: 1568–1580

GPM (Global Phenological Monitoring, 2003). Towards international standardization of phenological observation protocols. Vol **2** pp 14-19

Grainger, A. (1993). Controlling tropical deforestation. *Earthscan Publications* Ltd., London. 310pp

Gyimah, A (2000). Effect of pre-treatment methods on germination of Garcinia kola seeds. *Ghana J. Forestry***9**: 39- 44.

Gyimah, A. (1984). Storage of Mansonia altissima seeds. FRRI Technical Bulletin no 9

Hagerty M.S and Susan M. J. (2008). A guide to phenological monitoring for students, teachers, families and nature enthusiast.Phenlogy Handbook, University of California, Santa Babarapp**13-**15

Hall J.B. &Swaine M.D., (1981). Distribution and ecology of vascular plants in a tropical rainforest.Forest Vegetation in Ghana. The Hague: W. Junk.

Hawthorne W. D and Gyakari N. (2006). Photoguide for the forest trees of Ghana. Oxford Forestry Institute, Department of Plant Sciences. Oxford Press.

Hess, M., G. Barralis, H. Bleiholder, L. Hack R. Stauss (1997): Use of the extended BBCH- scale general for the description of the growth stages of mono- and dicotyledonous weed species. *Weed Research*, **37**, 433-441

Herms D. A. (2004). Using degree-days and plant phenology to predict pest activity. In: V. Krischik and J. Davidson, Eds. IPM (*Integrated Pest Management*) of Midwest Landscapes, pp. 49–59. Minnesota Experiment Station Publication SB-07645, 316 pp

Holzkamper A, Calanca P, Fuhrer J (2013). Identifying climatic limitations to grain maize yield potentials using a suitability evaluationapproach. *Agric Forest Meteorol* 168:149–159

Iglesias, R.G.and M.J. Babiano.(1997). Endogenous abscisic acid during the germination of chickpea seed.*PhysiologiaPlantarum**100***: 500-504.

IPCC (2007). Climate Change 2007: Synthesis Report. Contribution ofWorking Groups I, II and III to the Fourth Assessment Report of theIntergovernmental Panel on Climate Change [Core Writing TeamPachauri, R.K and Reisinger, A.(eds.)]. IPCC, Geneva, Switzerland 104 pp.

Irvine, F.A.R. (1961). Woody plants of Ghana with special reference to their uses. Oxford Univ. Press London p **146**.

IUCN (The World Conservation Union) (2008).. Red list of threatened tree species.

Kikim A, Yaadava PSKorner P.(2001). Phenology of tree species in sub-tropical forests of Manipur inNorth eastren India.Tropical Ecology. 2001;**42**:269-276.

Kirschbaum, M.U.F., (2000).. Forest growth and species distribution in a changing climate.*Tree Physiol*. **20**, 309–322.

Koch, E., Scheifinger, H. and Moris, E. J. (2004). Phenology as a biological indicator for a warming climate.*Institute of Crop Ecology*; 1985.

Korner C. (2006). Plant CO2 responses: an issue of definition, time and resource supply.*New Phytologist***172**, 393–411.

Kucera B, Cohn M. A., Leubner-Metzger G (2005). Plant hormone interactions during seed dormancy release and germination.*Seed Science Research***15**, 281–307.

Lechowicz M.J. (2003). Phenology.Encyclopaedia of Global Environmental Change, Volume 2. *The Earth System: biological and ecological dimensions of global environmental change.*

Leith, H. (1974). Phenology and seasonality modeling. Springer Verlag,New York, **41** pp.6-8.

Lilley J.M. and Fukai S. (1994). Effect of timing and severity of water-deficit on 4 diverse rice cultivars. 3. Phenological development, crop growthand grainyield. *Field Crops Research***37**, 225–234.

Lavalle C., Micale F, Houston TD, Camia A, Hiederer R, Lazar C, ConteC, Amatulli G, Genovese G. (2009). Climate change in Europe. 3.Impact on agriculture and forestry. A review (Reprinted).*Agron Sustain Dev* 29:433– 446

Maguire J.D. (1962). Speed of germination-aid in selection and evaluation for seed emergency and vigour. *Crop Science***2**: 176–177.

Meier, U. (1997). Growth stages of mono- and dicotyledonus plants. BBCH monograph, blackwell *Wissenschafts-Verlag* Berlin Wien

Menzel, A. and Sparks B. (2006): Phenology, its importance to the Global Change Community. *Editorial Comment on Climatic Change*,**54**, 379-385.

MESTI (Ministry of Environment, Science, Technology, and Innovation, 2002).National Biodiversity Strategy for Ghana, Ministry of Environment, Science and Technology. *Technical Information Sheet* ***4*,**Pp 12.

Miller-Rushing A. J, Hoye. T. T., Inouye DW, Post E (2010). The effects of phenological mismatches on demography. Phil Trans R Society *Biological Sci***365**:3177–3186

Mireku, A. J (2009). Seed desiccation tolerance and germination of seven important forest trees in Ghana. Phd Thesis Department of Horticulture KNUST Kumasi. pp **3.**

Morellato LPC, Tailor DC, TakahasiA, Benck. (2000). Phenology of Atlantic rain forest trees: a comparative study. Biotropica 32: 811–823.

Morin X, Lechowicz MJ, Augspurger C, O'Keefe J, Viner D, Chuine I.(2009). . Leaf phenology in 22 North American tree species during the 21st century.*Global Change Biology **15:***961–975.

Msanga, H. P. (1998). Seed germination of indigenous trees in Tanzania. Edmonton, Canadian forest Science, Northern Forestry Centre 292p.

Msanga H. P. and Maghembe J. A. (1989). Physical scarification and hydrogen peroxide treatment improves germination of *Vangueria infausta* seeds. For Ecology Manage., 28:301-308

Nalawadi UG, Bhandary KR, Chandrashekar T (1977). Germination of Cassia fist ula (Linn.)*Curr.Res.Hortic.Abst.***46.**3645 1975 **4(3)**:42-43.

Nam NH, Chauhan YS, Johansen C. (2001). Effect of timing of drought stress on growth and grain yield of extra-short-duration pigeon pea lines. *Journal of Agricultural Science***136**, 179–189.

Newstrom L .E, Frankie GW, Baker H.G (1994). A new classification for plant phenology based on flowering patterns in lowland tropical rain forest trees at La Selva, Costa Rica. *Biotropica* **26**:141–159

Ofosu-Asiedu, A., Foli, E. G. Peprah T. (1997). Fast growing indigenous species for private and community plantation development in high forest zone of Ghana. Invited paper presented at the workshop on promotion of community and

private plantations in the high forest zone. Christian Village, Kumasi. 2427 March 1997

Opler, P. A., Frankie G.W. Baker H. G., (1976). Rainfall as a factor in the release, timing and synchronization anthesis by tropical trees and shrubs. *J. Biogeogr*.**3**. 231-236.

Parmesan C, Yohe G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature***421**:37–42

Polte-Rudolf C. (1993) The IPG Databank at the Deutscher Wetterdienst Aboretum. *Phaeno*l 38:28-31

Poorter, H., (1993). Interspecific variation in the growth response of plants to an elevated ambient CO2 concentration. *Vegetation* **104**/105, 77–97.

Post E, Forchhammer M. C., Stenseth N. C and, Callaghan T.V. (2001). The timing of life-history events in a changing climate. Proceedings of the Royal Society of London Series B **68**, 15–23.

Pregitzer K S, King JA, Burton AJ, Brown SE. (2000). Responses of tree fine roots to temperature. *New Phytologist**147***, 105–115.

Quedraogo, A.S., Thomsen, K.,Engels, J. M. and Engelmann, F.(1999). Recalcitrant Seeds,*Forest Seed Science and Technology*. **28**:pp 227 – 234.

Ramorthy K, Rajendran C, Sivasubramanian S (2005). Seedtreatment for alleviation of hard-seededness in senna (*Cassia angustifolia L*.). *Adv Plant Sci*. **18(1):** 429-430.

Rathcke, B, and Lacey, E.P .(1985). Phenological patterns of terrestrial plants. Ann. Rev.Ecol. Research- Atmosphere **106** 69-83

Rawat, M.M.S. (2005). Optimum conditions for testing germination of bamboo seeds. J. *Bamboo and Rattan.***4** (1): 3-11.

Richardson AD, Black TA, Ciais P, Delbart N, Friedl MA, GobronNHollinger DY, KutschWL, (2010). Influence of spring and autumn phenological transitions on forest ecosystem productivity. *Philos Trans R Soc*, B **365**:3227–3246

Roberts E.H (1973). Predicting the storage life of seeds.*Seed Science and Technology***1**, 499–514.

Sacande, M. and Pritchard, H. W. (2004).Seed research network on African trees for conservation and sustainable use. *Forest Genetic Resources***31**:31-35

Schaeffer, C. (1990). Seed testing research of species indigenous to Kenya. In: Turnbull, J.W. (ED). Tropical tree seed research. Proceedings of an international workshop held at the Forestry Training Centre, Gympie, Queensland Australia: 1989 August 21 - 24. ACIAR Proc. No. **28**: 132 - 139.

Root T. L., Price, J.T., Hall K.R., Schneider S.H, Rosenzweig C, and Pounds J. A. (2003). Fingerprints of global warming on wild animals and plants.*Nature***42**:57–60

Schmidt, L. (2000). Guide to handling of tropical and sub-tropical forest seeds. Danida Forest Seed Centre.Humleback, Denmark. Pp3-11.

Schwartz, M.D., (1999). Advancing to full bloom: planning phenological research for the 21st century. *Int. J. Biometeorol*.**42**, 113–118

Schwartz M. D. (2003). Phenology: an integrative environmental science. Dordrecht. Netherlands: Kluwer Academic Publishers. 2003;**92**.

Singh, K.P. and Kushwaha CP. (2005). Emerging paradigms of tree phenology in the dry tropics.*Current Science* **89**: 964–975.

Singh K. P, Kushwaha C. P. (2006). Diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India. Annals of Botany **97**:265-276.

Shukla R. P., Ramakrishnan P.S Richards P.W. (2005). Phenology of trees in the sub-tropical humid forest in north eastern India. *Vetagio*.**49**, 103-109.

Smith, M.T.,Wang, B.S.P., and Msanga, H.P. (2002). Dormancy and germination. In: *Tropical tree seed manual,* U.S. Department ofAgriculture and Forest Science.Pp**149** -176.

Sonnentag, O., Hufkens K., Teshera-Sterne, Tish K (2012). Digital repeat photography for phenological research in forest ecosystems.
Agr.Forest.Meteorol. **152**, 159–177.

Somade, A.F. (1985). Seed problems in a depressed economy. The case of forest seed collection, storage and supply in Nigeria.*15th Annual Conference of the ForestryAssociation of Nigeria,* November 25 – 29, 1985, Gongola State, Nigeria.

Teem, D. H., Hoveland C.S. and Buchanan G. A (1980). Sicklepod (*Cassia obtusifolia*) and coffee senna (*Cassia occcidentalis*): geographic distribution, germination and emergence. *Weed Sci*. **28**: 68-71.

Tompsett P. B. and Pritchard H. W. (1998). The effect of chilling and moisture stress on germination, desiccation tolerance and longevity of *Aesculus hippocastanum* L. seeds. *Annals of Botany* **82**: 249-261

Turnbull, J.W. (1975). Seed extraction and cleaning. In: Report to FAO/DANIDA Training course on Forest Seed Collection and Handling, Vol. **2** , FAO, Rome.

Van Schaick C. P., Terborgh J. W., Wright S. J. (1993). The phenology of tropical forests: adaptive significance and consequences for primary consumers. *Annual Review of* ecology and Systematics **24:** 353-377.

Ventrella D, Charfeddine M, Moriondo M, Rinaldi M, Bindi M. (2012). Agronomic adaptation strategies under climate change for winterdurum wheat and tomato in southern Italy: *Reg Environ Chang***12**:407–419

Vitasse Y, François C, Delpierre N, E., Dufrêne E., Kremer A., Chuine I., Delzon S. (2011). Assessing the effects of climate change on the phenology of European temperate trees. *Agric. Meteorol*. **151**: 969–980.

Walther GR (2010). Community and ecosystem responses to recent climate change. Phil Trans R Soc B-Biological Sci 365:2019–2024

Ward JK, Strain BR. (1999). Elevated CO2 studies: past, present and future. Tree Physiology **19**, 211–220.

Willis CG, Ruhfel B, Primack R. B, Miller-Rushing AJ, Losos JB, DavisCC (2010). Favorable climate change response explains non-native species' succession in Thoreau's woods. *PloSONE* 5:78

Wilson, E. O. (1988). The current state of biological diversity. In: Biodiversity. National Academy Press, Washington, D. C. 3-18.

Young, J.A. and Young. C. G (1992). Seeds of Woody Plants in North America. Dioscorides Press, Portland, Oregon, USA.

Zadoks, J. C., T. T. Chang, And C. F. Konzak, (1974). A decimal code for the growth stages of cereals. *Weed Research***14**, 415-421 and *Eucarpia BulletinNo*. **7**, 49-52.

Zahner, R., (1968). Water deficits and growth of trees. In: *Plant Growth* Vol. 2. Ed. T.T. Kozlowsk, Academic Press, New York.

Zavaleta E. S, Shaw M.R, Chiariello N. R, Thomas B. D, Cleland E .E, Field C. B, Mooney H. A. (2003). Grassland responses to three years of elevated temperature, CO2, precipitation, and N deposition. *Ecological Monographs* **73**, 585–604.