Climate Change Implications on the Phenology of Different Eucalypt Species in Pakistan

*Asif Javed Muhammad – Assistant Professor (Ph.D.) (Affiliated with the Department of Forestry and Range Management, University of Agriculture Faisalabad, Faisalabad, Pakistan)
Izhar Ul Haq – M.Phil. (Affiliated with the Department of Forestry and Range Management, the University of Agriculture Faisalabad, Faisalabad, Pakistan)
Atif Ali – Ph.D. (Affiliated with the Department of Forestry and Range Management, University of Agriculture Faisalabad, Faisalabad, Pakistan)
Muhammad Bilal Zia – M.Phil. (Affiliated with the Pakistan Forest Institute (PFI), Peshawar Pakistan)
Nauman Ghafoor – M.Phil. (Affiliated with the Department of Forestry and Range Management, University of Agriculture Faisalabad, Faisalabad, Pakistan)

Shaheena Ramzan – M.Phil. (Punjab Forest Research Institute (PFRI), Gatwala, Faisalabad Pakistan)

ABSTRACT

The effect of climate on the phenology of six eucalypt species was observed during a period of two years under similar environmental conditions. High rainfall, temperature, and humidity were observed in the first year compared to the following year. High temperature, rainfall, and humidity had a significantly positive effect on the percent increase in height, dbh, early flowering, completion of flowering, and seed production however seed germination was negatively affected. Six eucalypt species flowered at different times of the year. *E. microthica*, *E. camaldulensis*, *E. torriliana*, and *E. globulus* flowered from January to April whereas *E. kitsoniana* and *E. melanophloia* flowered from November to December respectively. Generally, flowering was delayed by 13 – 15 days from the previous year. It was delayed in *E. cammaldulensis, E. kitsoniana and E. microthica* and was ended earlier in *E. globulus*, *E. melanophloia*, and *E. torriliana* respectively. A maximum percent increase in height was observed for *E. microthica* followed by *E. cammaldulensis* and *E. kitsoniana*. The lowest increase was observed in *E. torriliana*. Maximum dbh growth was observed in *E. globulus* (12.86%) and *E. kitsoniana* (12.16%) followed by *E. cammaldulensis*. The lowest was recorded for *E. microthica* (6.63%). Seed production was high in the year 2015 as compared to 2017. The highest seeds were produced by *E. cammaldulensis*

(40 seeds per capsule) followed by *E. kitsoniana* and *E. microthica*, Seed production was negatively affected in *E. globulus* (28 seeds per capsule). The highest germination rate was observed for *E. cammaldulensis* (75%) and the lowest for *E globulus* (68%) and *E. microlithic* (67.5%). Our findings highlight that climate-driven shifts will likely occur because of changes in climate in the future and this may likely change the species' growth, behavior, response, pollinator behavior, and interspecific interaction and competition. The phenological response thus can be used for conservation, breeding, and sustained production of eucalypts in Pakistan.

Key words: *Eucalyptus., Climate change., Phenology., Pollinator., Flowering., Seed Production., Seed Germination*

Introduction

Eucalyptus is a significant genus in forestry, with several species exhibiting rapid growth, high phenotypic plasticity, high adaptation, a short rotation cycle, and high economic value (Sumathi and Yasodha, 2014). Eucalyptus has been introduced into numerous nations around the world because of these traits (Sumathi and Yasodha, 2014). Because of its rapid growth, broad adaptability, and multipurpose utility, Eucalyptus is the world's leading industrial plantation species. Until recently, most Eucalyptus plants around the world were earmarked for paper manufacture; however, these farms are now looking to assist the hardwood industry, including veneer production (Luo et al., 2013). Pakistan is one of the most vulnerable countries globally to climate change (Javed et al., 2017). Phenology is the study of how the timing of recurrent events in living things' lives relates to changes in climate. Phenology is receiving a lot of attention these days for tracking how living things are affected by global and climate change. It has developed into a very helpful tool for understanding how climate affects the relationships that various organisms have with their environments (Maaz et al., 2014). Both internal and external influences affect a species' response. Numerous abiotic elements have the potential to impact the phenology of plants. In temperate locations, temperature and photoperiod are commonly recognized as the primary drivers of phenological changes (Sparks et al., 2000., Menzel and Estrella 2001., Korner 2010). But in desert, Mediterranean, tropical, and subtropical parts of the planet (Corlett and Lafrankie 1998; McDonald and McMahon 2005., Peñuelas, et al., 2004., Reich 1995), precipitation has also been a significant abiotic component that influences the phenology. The physiology, phenology, and distribution of species alter because of global warming. Because of changes in the host-pollination connection, the increasing temperature is having an impact on the production of flowers, nectar, and pollen. Because the effects of rising temperatures and climate change are not well documented, it is required to associate them with changes in time, space, and ecology. Because of a mechanism that makes sure that flower production occurs in various tree species, trees have predictable flowering times throughout their life cycles (Jones et al., 2011). The flowering phenology of trees determines the effectiveness of reproduction of tree species under altered climate conditions as well as the possible effects of these changes. Comparably, the degree to which different trees flower at the same time indicates the potential for interbreeding within a population. Understanding phenology is crucial to comprehending how a set of plants were originally organized. One of the three main fast-growing tree species in the world, eucalyptus is widely planted in tropical and subtropical areas of the globe (Kien et al., 2009). Initially, eucalypts were brought into Pakistan to plant on saline and waterlogged soils to promote reforestation. These days, it is abundantly cultivated in Pakistan's many ecological zones (Sheikh, 1984). Pakistan's domestic paper industry depends mostly on imported pulp. Most of the pulp produced worldwide comes from eucalypt plantations, and the government is showing a strong interest in these plantations for the purpose of producing pulp locally. However, because of climate change, eucalypts demonstrated more sensitivity to flowering and biomass yield (Asif et al., 2023., Stephen et al., 2016).

In comparison to the combinations of the properties in the pure species, eucalypt hybrids with improved characteristics have the potential to produce genotypes with unique combinations that may increase the value of the genetic resources. Examples of these combinations include disease resistance, water use efficiency, timber properties, and greater vigor on specific sites (Hettasch et al., 2005). Disturbances in the flowering length can affect not only a single species but also the synchronization of other species (Chuine and Rousseau, 2010). For many tree species, there is insufficient long-term data to accurately determine how climate conditions affect phenological variations. Climate fluctuations at the local scale are evident in understanding the connections between phenological timing (Elizebath et al., 2015). The goal of this study is to determine how various eucalypt species are affected by environmental variables including temperature, humidity, and rainfall in relation to phenological occurrences.

Materials and Methods

The suggested study was conducted from 2015 to 2017 in the Punjab Forest Research Institute (PFRI) research arboretum in Faisalabad, Punjab, Pakistan. *Eucalyptus melanopholia*, *E. torriliana*, *E. kitsoniana*, *E. globulus*, *E. camaldulensis*, and *E. microthica* were included in this study. Ten, fifteen-year-old eucalyptus trees were chosen at random to be the subjects of all observations.

Climate Data

In Faisalabad, Punjab, Pakistan, PFRI is situated between latitudes 30 and 31.5 North and longitudes 73 and 74 East. It has brief winters and long summers. The district experiences extremely harsh weather, with a maximum temperature of 50^{o}C (122^{o}F) and a minimum temperature of -1^{o}C (30^{o}F). In a mild summer, the mean temperature reaches its maximum point at 39^{o}C (102^{o}F) and its lowest point at 27^{o}C (81^{o}F). It may drop as low as 6^{o}C (43^{o}F) and as high as 21^{o}C (70^{o}F) throughout the winter. April marks the beginning of the summer season, which lasts until October. May, June, and July are the hottest months of the year. November is the first of the chilly months, which last until March. December and February are the coldest months of the year. The average precipitation per year is 300 mm. For the duration of the study, the Meteorological Cell, Plant Physiological Section, Ayub Agricultural Research Institute (AARI), Faisalabad, Punjab provided the temperature (°C), rainfall (mm), and humidity data.

Data Collection

Tree height (m), DBH (cm), bloom initiation and finishing times, quantity of seeds per pod, and percentage of seed germination were among the variables that were recorded.

Statistical Analyses

Analysis of variance was used to analyze the data (ANOVA). The "*agricolae*" package in R was used to compare significant treatment means using the Duncan Multiple Range Test (DMR) (R Core Team, 2022).

Results

There was a significant variation in temperature between 2015 and 2017 (Fig. 1). In comparison to 2016, an average high temperature was reported during 2017. The months of March, April, and

May saw the most variations in temperature (Fig. 1). March through May of 2017 saw a temperature range of 30 to 46 degrees Celsius, while the same time in 2016 saw a temperature range of 28 to 41 degrees Celsius (Fig. 1). In contrast to 2017, 2016 saw a lot more rainfall (Fig. 2). In 2016, the rainfall pattern was bimodal where the first phase began in February and ran through April, while the second phase began in June and concluded in August (Fig. 2). Low rainfall intensity, on the other hand, was recorded in 2017 at the same period of the year. In the year 2016, relatively high moisture concentrations were recorded in the months of August and February. This was consistent with the heavy rainfall that was seen during this time of year. In contrast, minimal humidity was seen in the same months in 2017 (Fig. 3).

All six species displayed various rates of growth during the years that were observed, namely 2015 through 2017. In general, species fared better in 2016's rainy year than they did in 2017. Growth over the course of two years was measured relative to the percent change in height. *E. microthica* had the highest percentage increase, followed by *E. cammladulensis* and *E. kitsoniana* (Table 1). The species *E. torriliana* showed the least amount of increase in height. E. melanophloia was found to have the highest height (27.65m), followed by *E. torriliana*. The lowest plant height was *E. microthica* (8.4 m). The most often planted species, *E. globulus* (18.6 m), *E. torriliana* (26.2 m), *E. melanophloia* (27.65 m), and *E. camaldulensis* (13.25m), all fared fairly (Table 2). All species had considerably varied DBH, and 2016 and 2017 saw distinct rates of DBH rise, respectively. *E. melanophloia* (15.27 percent), *E. microlithic* (12.96 percent), and *E. cammaldulensis* (10.41 percent) showed the largest and lowest percent increases in DBH, respectively (5.64 percent). *E. globulus* (12.86 inch) and *E. kitsoniana* (12.16 inch) had the highest DBH, followed by *E. camaldulensis*. The *E. microthica* species has the lowest DBH found (6.63 inches).

Based on flower initiation behavior, three groups of six species can be identified (Fig. 5). While *E. torriliana*, *E. globulus*, and *E. microthica* blossomed in March and April, *E. camaldulensis* flowered in December and January. In October and November, two species i.e., *E. kitsoniana* and *E. melanophloia* went through flowering (Fig. 5). All species showed considerably varied flowering initiation times, which were likewise significantly different for the two years (Table 2). In comparison to 2016, most of the species' flowering occurred late in 2017 (Table 2). In contrast to 2017, *E. torriliana* flowered earlier, whereas *E. microthica* and *E. kitsoniana* remained unaffected. However, in 2017, *E. melanophloia*, *E. globulus*, and *E. camaldulensis* all had delayed flowering. In general, blossoming was 13–15 days later than the previous year. Three species i.e., *E. cammaldulensis* , *E. microthica* , and *E. kitsoniana* had a delayed flowering completion cycle in 2017 compared to 2015. *E. torriliana*, on the other hand, had completed flowering earlier than the year before. Both *E. globulus* and *E. melanophloia* underwent flowering at the same time in both years, indicating that they were unaffected. Compared to 2015, the species' flowering cycle was prolonged overall in 2017 (Table 2). There were notable variations in seed germination between species and years. Between 60 and 80 percent of the seeds germinated in both years. In comparison to 2016, a high germination rate was noted in 2017. There were notable variations in seed output between the species during the years under investigation (Fig. 7). Compared to 2017, seed production was higher in 2016. *E. cammaldulensis* generated the most seeds (40 seeds per capsule), followed by *E. kitsoniana* and *E. microthica* (Fig. 7). *E. globulus* produced the fewest seeds (28 seeds per capsule). Seventy-five percent was the greatest germination rate for *E. cammaldulensis,* and sixty-eight percent and sixty-five percent, respectively, for *E. globulus* and *E. microthica* (Fig. 8).

Discussion

The rate of climate change is concerning, with varying temperature, precipitation, and humidity events occurring annually. The natural equilibrium between the animals and their surroundings is being upset by these shifting climate circumstances (Caparros-Santiago et al., 2021., Guo et al., 2021., Miaogen et al., 2020., Sharma 2008). Pakistan is considered one of the ten countries in the world to be seriously threatened by climate change impacts (Javed et al., 2017). Low rainfall, high temperatures, and dry conditions have been experienced in Pakistan in recent years. Faisalabad has seen a decline in monsoon rainfall throughout the years. Moreover, the distribution of rainfall is not constant throughout the year as most of the rainfall happens in the warmer months of July through September. The months of June, July, and August saw the heaviest rainfall in 2015 overall. In the same months in 2017, the intensity was lower. In 2015, there was a lot of rain toward the start of the flowering season and near the end of it. However, in 2017, blossoming begins in conditions that are comparatively dry and have little rainfall. Since the monsoon season brings with it substantial rainfall, the primary rainy season often begins in June and lasts until the end of July. This does not appear to be the case today, though, as the monsoon season saw extremely little rain, which indicates that the climate has a significant impact on rain patterns. Eucalypts fared better in hot, humid weather in terms of height and DBH growth. According to Sette et al. (2016), temperature fluctuations in plants cause cambial growth, which in turn causes fundamentally important changes in dbh growth and wood. The growth period of eucalypts was correlated with temperature, humidity, and rainfall. It was found that the density of wood was more sensitive to alterations in climate. Since flowering start was delayed in the following season due to low temperatures, low rainfall, and low humidity, it was found that flowering initiation was particularly sensitive to climate changes. Primack et al. (2008) also contended that there is a wealth of data indicating that plant populations are adapting to the fast-changing climate. For instance, mid-19th-century assessments of 43 plant species' current flowering dates revealed that a 2.4°C rise in temperature led to an advance in flowering time of an average of 7 days. The timing of flowering is influenced by exceptional climatic events, according to research conducted by Law et al. (2000) and Elsa et al. (2007) on the phenology of flowering in twenty different Australian eucalyptus tree species under varying environmental conditions. A high monthly rainfall was accompanied by a high flowering. Low flowering was seen during the eighteen-month drought, but they quickly recovered afterward. According to research by Broak et al. (2017), the timing, duration, and events of the life cycle such as inflorescence—are related to climatic variables, such as climate warming. Tree phenology is predicted to fluctuate in response to climatic differences, and this is indeed the case for many trees. Changes in the time of flowering in different tree species can serve to modify plant competition. The duration and timing of inflorescences in British plants have changed, impacting the link between the timing of insect breeding cycles and flowering times (Balfour et al., 2018). Compared to plants pollinated by wind, those pollinated by insects exhibit later flowering dates. Mays et al. (2017) found that the northern hemisphere experiences a delayed flowering season. There is a species in these places that flowers 26 days earlier in the annual growth season than it did ten years ago. Furthermore, spring arrived in Washington, DC, twenty-two days early this year due to the country's chilly temperature. According to Stephen et al. (2016), phenological reactions to climate change in species will cause interactions to become desynchronized and pose a serious threat to the functioning of ecosystems. Asynchrony poses a serious risk to seed production and seed quality in insect-pollinated plants like acacia and eucalypts (Irene et al., 2002). The onset of flowering in *E. tricarpa*, *E. leucoxylon*, and *E. polyanthemos* is strongly influenced by precipitation. *Eucalyptus leucoxylon* and *E. tricarpa* exhibit delayed flowering. Higher temperatures and precipitation in *E. microcarpa* and *E. polyanthemos* indicated an early start to flowering.

High temperatures, high levels of precipitation, and humid environments were found to promote high seed production; however, they were also associated with low seed germination. Similar responses in flowering intensity were noted by Richard et al. (2006) in *E. miniata* and *E. tetrodonta* during drought conditions. Because peak reproductive activity occurred early in the season and the phenology of germination was also impacted by the arrival of rainfall, the driest period did not result in a common production of flowers and fruits. In *E. camaldulensis*, blooming and seed fall were significantly reduced. Unripe capsules and bud damage were the main causes of uneven seed output. In a similar vein, variations in summertime circumstances also had an impact on seed viability (Julian et al., 2001., Ren et al., 2021., Rosbakh et al., 2021). According to Bernado et al. (2011), temperature variations have a major impact on *Eucalypt leucoxylon* on germination and seedling emergence. As the temperature rose, the germination percentage sharply decreased. In a similar vein, Rawal and Deepa (2011) proposed that the germination phenology will be susceptible to climate change and exhibit a positive trend toward temperature and moisture variations.

Conclusion

The timing of biological processes, including flowering time, flowering completion, pollination and synchronization, seed production, and seed germination, in eucalypts has been found to be affected by climate change. These changes in circadian rhythms are also affecting how eucalypt species interact, as seen in the progressive early flowering and delayed pollinator arrival. The primary cause of these alterations is the rise in global warming-related temperatures. Therefore, understanding phenology is crucial to forecasting how future climate change may affect eucalypt productivity. The shisham population reduction due to dieback in Pakistan's various ecological zones has drawn increased attention to eucalypts. Similarly, Pakistan is burdened with the import of pulp every year and needs to increase the local production of eucalypts. They are also employed in the production of fuelwood. Understanding phenology and how it influences the many stages of the eucalypt's growth is crucial for making critical decisions and managing eucalypt vegetation for sustainable productivity.

References

1. Asif M. J., Nauman, G., Izhar Ul Haq, Bilal, M. Z., Atif, A., and Amir, M., 2023. Characterizing *Eucalyptus Camaldulensis* and *Eucalyptus Globulus* Species Under Water Stress Conditions. Journal of Xi'an Shiyou University, Natural Science Edition, 19(11):95-109.

2. Balfour, N.J., Ollerton, J., Castellanos, M.C. and Ratnieks, F.L., 2018. British phenological records indicate high diversity and extinction rates among late-summer-flying pollinators. Biological Conservation, 222, pp.278-283.

3. Bernardo, D.R., Pezzini, F.F., Garcia, Q.S., Chautems, A., Giovanni, M. and França C., 2011. Testing the regeneration niche hypothesis in Brazil: Implications for the conservation of rare species. Austral Ecology. 37(1): 165-180.

4. Caparros-Santiago, J.A., Rodriguez-Galiano, V. and Dash, J., 2021. Land surface phenology as indicator of global terrestrial ecosystem dynamics: A systematic review. ISPRS Journal of Photogrammetry and Remote Sensing, 171, pp.330-347.

5. Chuine, I., Cour, P. and Rousseau, D.D., 1999. Selecting models to predict the timing of flowering of temperate trees: implications for tree phenology modeling. Plant, Cell & Environment, 22(1), pp.1-13.

6. Cleland, E.E., Chuine, I., Menzel, A., Mooney, H.A. and Schwartz, M.D., 2007. Shifting plant phenology in response to global change. Trends in ecology & evolution, 22(7), pp.357-365.

7. Corlett, R.T. and Lafrankie Jr, J.V., 1998. Potential impacts of climate change on tropical Asian forests through an influence on phenology. Climatic change, 39(2-3), pp.439-453.

8. Guo, M., Wu, C., Peng, J., Lu, L. and Li, S., 2021. Identifying contributions of climatic and atmospheric changes to autumn phenology over mid-high latitudes of Northern Hemisphere. Global and Planetary Change, 197, p.103396.

9. Hettasch, M.H., Lunt, K.A., Pierce, B.T., Snedden, C.L., Steyn, D.J., Venter, H.M., and Verryn, S.D., 2005. Tree Breeding Course Manual. Pretoria: Natural Resources and Environment, CSIRO.

10. Irene, H., Chippendale, G.M., Hall, N., Hyland, B.P.M., Johnson, R.D., Kleinig, D.A., McDonald, M.W., Turner, J.D., 2002. Edited by D. J. Boland, Edited by M.I.H. Brooker, Forest trees of Australia. CSIRO.

11. Javed, Z.H., Sadique, M., Farooq, M. and Shabir, M., 2017. Agricultural productivity, carbon dioxide emission and nuclear energy consumption in Pakistan: an econometric analysis. SAUSSUREA, 7, pp.165-178.

12. Jensen, E.A., Keith, F.W., and David, C.P., 2007. Using phenology of eucalyptus to determine environmental watering regimes for the River Murray flood plain, South Australia School of Earth & Environmental Sciences DP312, The University of Adelaide, Adelaide.

13. Jones, R.C., Vaillancourt, R.E., Gore, P.L. and Potts, B.M., 2011. Genetic control of flowering time in *Eucalyptus globulus ssp. globulus*. Tree Genetics & Genomes, 7, pp.1209-1218.

14. Julian, D.T., Plummer, J.A., and Taylor, S., 2001. Seed germination ecology in southwestern, Western Australia. Bot. Rev 59:24–73.

15. Kien, N.D., Quang, T.H., Jansson, G., Harwood, C., Clapham, D., and Arnold, S.V. 2009. Cellulose content as a selection trait in breeding for kraft pulp yield in *Eucalyptus urophylla*. Annals of Forest Science 66:711-718.

16. Korner, C., 2010. Phenology Under Global Warming Int. J. Biometeorol. 42, 139–145.

17. Law, M.L., Schoer, A., Tweedie, T., 2000. Generalized Additive Models for Location, Scale and Shape, *Applied Statistics*, 54, 507-554.

18. Maaz, N., Abido, M., Suliman, M., Ahmad, H., 2014. How plants respond to climate change: migration rates, individualism, and the consequences for plant communities. Ann. Botany, 67(1): 15-22.

19. Matthews, E.R. and Mazer, S.J., 2016. Historical changes in flowering phenology are governed by temperature× precipitation interactions in a widespread perennial herb in western North America. New Phytologist, 210(1), pp.157-167.

20. Mays, S.N., Yeaman, S., Holliday, J.A., Wang, T., Curtis-McLane, S., 2017, Adaptation, migration or extirpation: climate change outcomes for tree populations. Evol Appl 1:95–115.

21. McLaren, K.P. and McDonald, M.A., 2005. Seasonal Patterns of Flowering and Fruiting in a Dry Tropical Forest in Jamaica 1. Biotropica: The Journal of Biology and Conservation, 37(4), pp.584-590.

22. Menzel, A. and Estrella, N., 2001. Plant phenological changes. In "Fingerprints" of Climate Change: Adapted Behaviour and Shifting Species Ranges (pp. 123-137). Boston, MA: Springer US.

23. Miaogen, S.H.E.N., Jiang, N., Dailiang, P.E.N.G., Yuhan, R.A.O., Huang, Y., Wei, Y.A.N.G., Xiaolin, Z.H.U., Ruyin, C.A.O., Xuehong, C.H.E.N., Jin, C.H.E.N. and Chiyuan, M.I.A.O., 2020. Can changes in autumn phenology facilitate earlier green-up dates of northern vegetation? Agricultural and Forest Meteorology, 291, p.108077.

24. Peñuelas, J., Filella, I., Zhang, X., Llorens, L., Ogaya, R., Lloret, F., Comas, P., Estiarte, M. and Terradas, J., 2004. Complex spatiotemporal phenological shifts as a response to rainfall changes. New Phytologist, 161(3), pp.837-846.

25. Primack, R.B., Pătroescu, M., Rozylowicz, L. and Iojă, C.I., 2008. Fundamentele conservării diversităţii biologice. AGIR.

26. R Core Team, 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

27. Rawal, H., and Deepa, D., 2011. Physiological effects of climate warming on flowering plants and Insects pollinators and potential consequences for their interaction. Proceedings. Regional expert consultation on eucalyptus. Volume I. Pp100-115.

28. Reich, P.B., 1995. Phenology of tropical forests: patterns, causes, and consequences. Can. J. Bot. 73, 164–174.

29. Ren, P., Liu, Z., Zhou, X., Peng, C., Xiao, J., Wang, S., Li, X. and Li, P., 2021. Strong controls of daily minimum temperature on the autumn photosynthetic phenology of subtropical vegetation in China. Forest Ecosystems, 8(1), pp.1-12.

30. Richard, J.W., Bronwyn, A., Myers, A., Derek, E., 2006. Reproductive Phenology of Woody Species in a North Australian Tropical Savanna. Pp 165-177.

31. Rosbakh, S., Hartig, F., Sandanov, D.V., Bukharova, E.V., Miller, T.K. and Primack, R.B., 2021. Siberian plants shift their phenology in response to climate change. Global Change Biology, 27(18), pp.4435-4448.

32. Sette Jr, C.R., Tomazello Fo, M., Lousada, J.L., Lopes, D. and Laclau, J.P., 2016. Relationship between climate variables, trunk growth rate and wood density of *Eucalyptus grandis* W. Mill ex Maiden trees. Revista Árvore, 40, pp.337-346.https://dx.doi.org/10.1590/0100-67622016000200016

33. Sheikh, M.I., 1984. Eucalyptus in Pakistan, Pakistan Forest Institute Peshawar.

34. Sparks, T.H., Jeffree, E.P. and Jeffree, C.E., 2000. An examination of the relationship between flowering times and temperature at the national scale using long-term phenological records from the UK. International Journal of Biometeorology, 44, pp.82-87.

35. Sumathi, M. and Yasodha, R., 2014. Microsatellite resources of Eucalyptus: status and future perspectives. Botanical studies, 55(1), pp.1-16.

36. Thackeray, S.J., Henrys, P.A., Hemming, D., Bell, J.R., Botham, M.S., Burthe, S., Helaouet, P., Johns, D.G., Jones, I.D., Leech, D.I. and Mackay, E.B., 2016. Phenological sensitivity to climate across taxa and trophic levels. Nature, 535(7611), pp.241-245.

Table 1. Mean percent comparison in height and DBH of six eucalyptus species 2015– 2017.

Species	% Annual Height Increment	% Annual DBH increment
E. microthica	28.57	12.96
E. cammaldulensis	16.19	10.41
E. torriliana	7.63	8.5
E.kitsoniana	15.38	9.00
E.melanophloia	8.32	15.27
E.globulus	9.68	5.64

Table 2. Significance of climatic anomalies on the phenology of eucalyptus species (ANOVA) and mean comparison by DMRT.

Height	df	MSS	DF	Species	Year
Species	5	1201.2	1019.92***	*E. melanophloia* = 27.65 ± 1.73a *E. torriliana* = 26.2 ± 1.41b *E globulus* = 18.6 ± 1.67c *E. cammaldulensis* = 13.25 ± 1.48d *E. kitsoniana* = 13.0 ± 1.34d *E. microthica* = 8.4 ± 1.47e	2017 =18.92±7.17a 2015=16.78±7.28b
Year	1	136.5	115.93***		
Species x Year	5	0.3	0.232^{N-S}		
Residuals	108	1.2			
DBH					
Species	5	97.84	118.922***	*E globulus* = 12.86 ± 1.3 a *E. kitsoniana* = 12.16 ± 1.2 a *E. cammaldulensis* = 11.845 ± 1.5 b *E. torriliana* = 10 ± 1.6b *E. melanophloia* = 9.43 ± 1.43b *E. microthica* = 6.63 ± 1.77c	2017 = 11.15±2.16 a 2015 = 9.16±2.29 b
Year	1	119.78	145.595***		
Species x Year	5	1.28	1.561^{N-S}		
Residuals	108	0.82			
Flower Initiation					
Species	5	275697	118.922***	*E. melanophloia* = 304 ± 1.43 a *E. kitsoniana* = 292 ± 1.20 b *E. cammaldulensis* = 32.8 ± 1.7 b *E. microthica* = 103 ± 1.77 c *E. torriliana* = 78 ± 1.6 d *E globulus* = 87.1 ± 1.5 d	2017=155.6±109.8 a 2015=143.5±108.2 b
Year	1	4404	145.595***		
Species x Year	5	1386	1.561^{N-S}		
Residuals	108	162			
Flower Completion					
Species	5	160110	1866.2***	*E. melanophloia* = 344 ± 1.54 a *E. microthica* = 165 ± 1.77 b *E. torriliana* = 152.4 ± 1.6 c *E globulus* = 142.4 ± 1.3 d *E. cammaldulensis* =121.7 ± 1.4 e *E. kitsoniana* = 83 ± 1.2 f	2017 = 171.6±109.8 2015 = 164.9±108.2
Year	1	47	0.546		
Species x Year	5	1396	16.268		
Residuals	108	162			
Seed Germination					
Species	5	140.3	6.936***	*E. cammaldulensis* = 74.75 ± 1.5 a *E. torriliana* = 71.75 ± 1.6 ab *E. melanophloia* = 71 ± 1.34 ab *E. kitsoniana* = 70.5 ± 1.2 bc *E globulus* = 68.0 ± 1.3 bc *E. microthica* = 67.5 ± 1.77 c	2017 = 74.67±4.9 a 2015 = 66.5±5.5 b
Year	1	2000.8	98.897***		
Species x Year	5	64.3	3.180**		
Residuals	108	20.2			
Seed Production					
Species	5	2167.5	114.5***	*E. cammaldulensis* = 40.25 ± 1.7a *E. kitsoniana* = 39 ± 1.6b *E. microthica* =38 ± 1.77c *E. torriliana* = 30 ± 1.6d *E. melanophloia* = 29.75 ± 1.43d *E globulus* = 28 ± 1.7d	2015 = 40.92±9.8 a 2017 = 32.42±9.4 b
Year	1		1587.8***		
Species x Year	5	173.0	9.136***		

Residuals	108	18.9			

Significance ≥0.05

Figure 1. Temperature trend for the years 2015 and 2017.

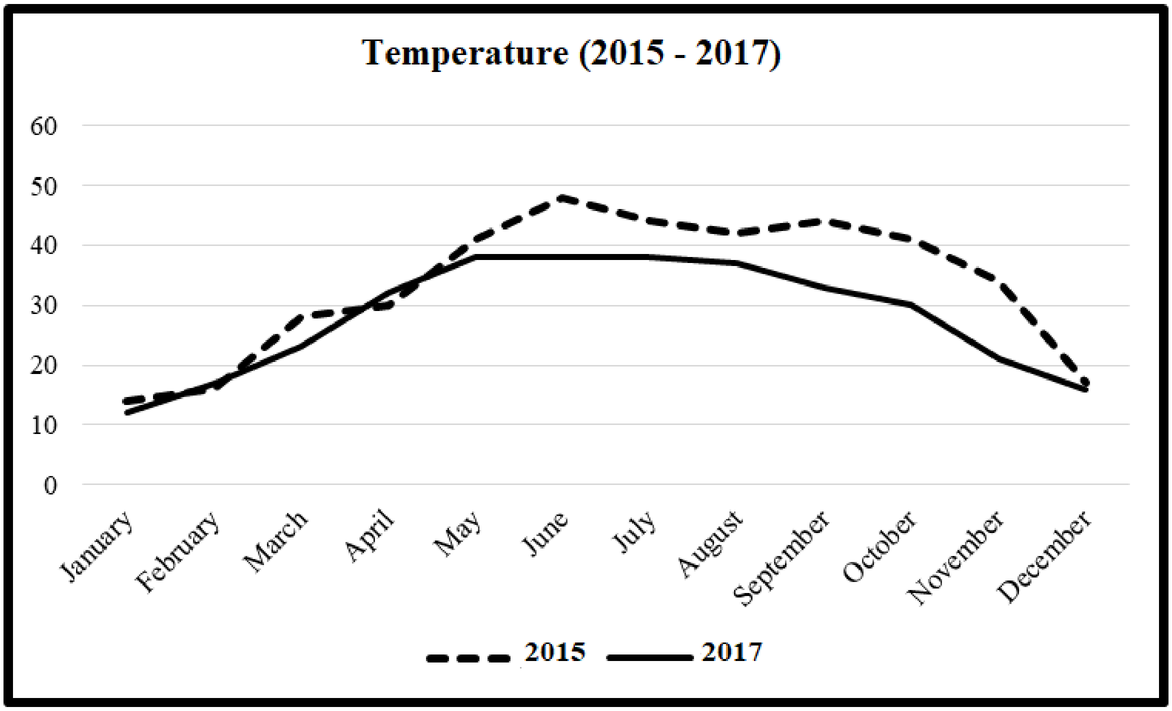

Figure 2. Rainfall comparison for the years 2015 and 2017.

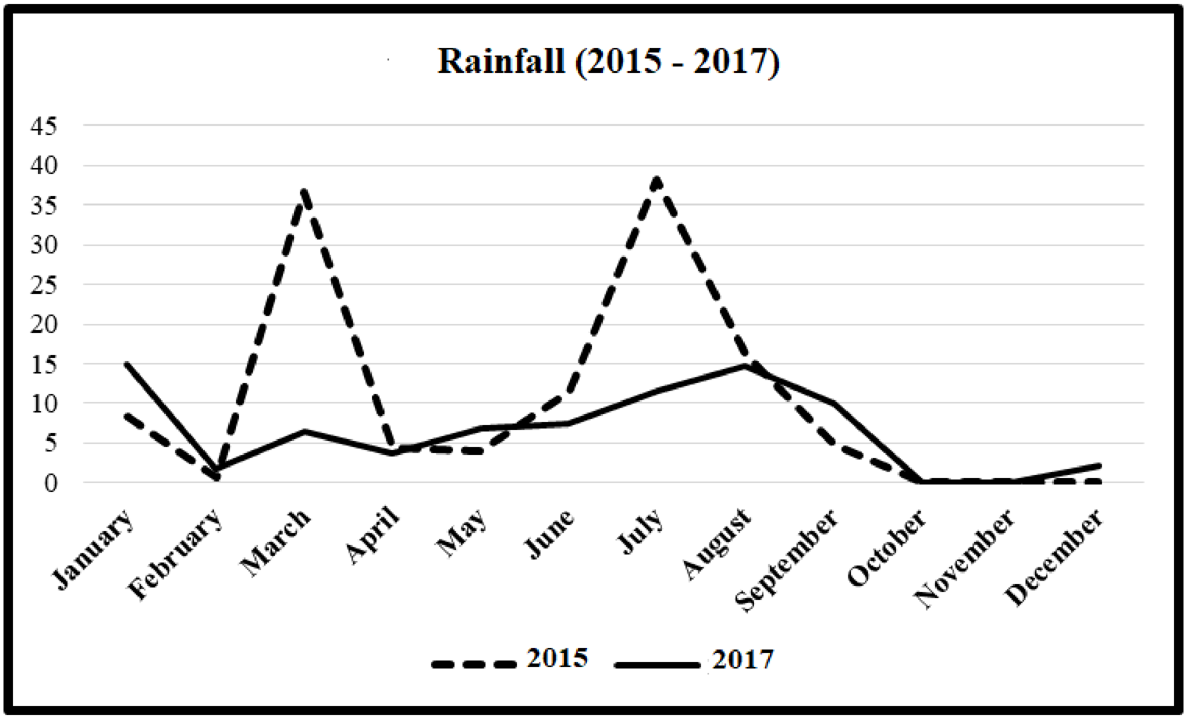

Figure 3. Humidity comparison for the years 2015 and 2017.

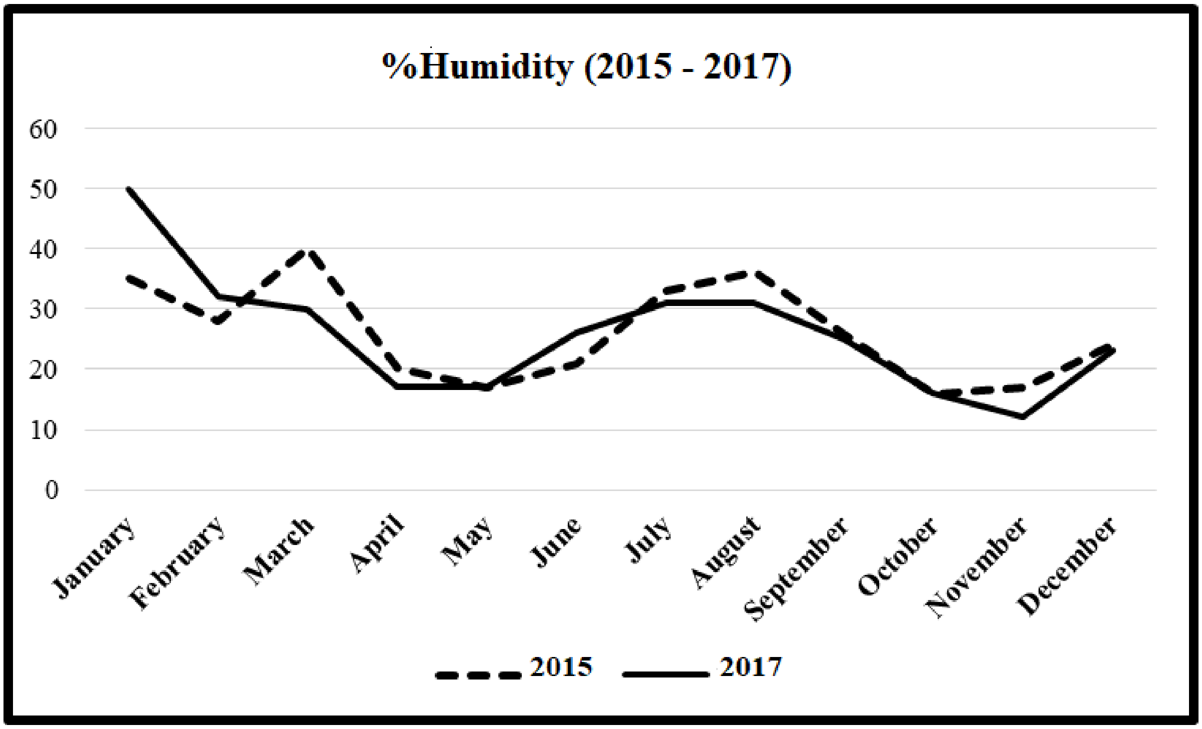

Figure 4. Effect of climate variation on DBH comparison in six eucalyptus species for the years 2015 and 2017.

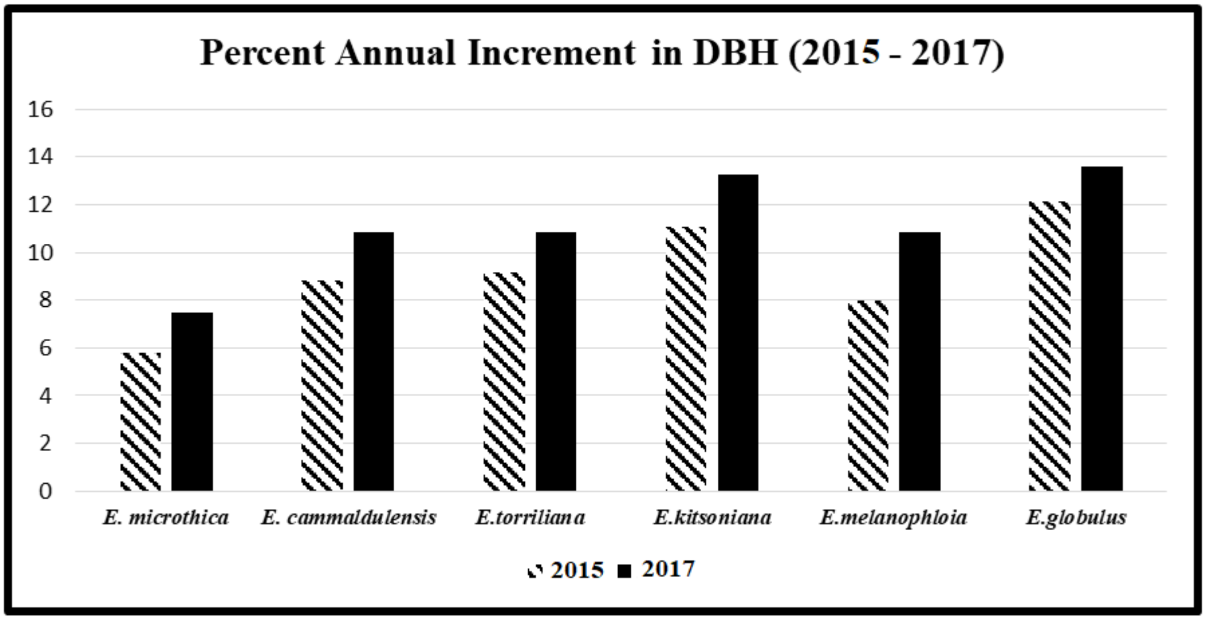

Figure 5. Effect of climate change on flower initiation in six eucalyptus species for the years 2015 and 2017.

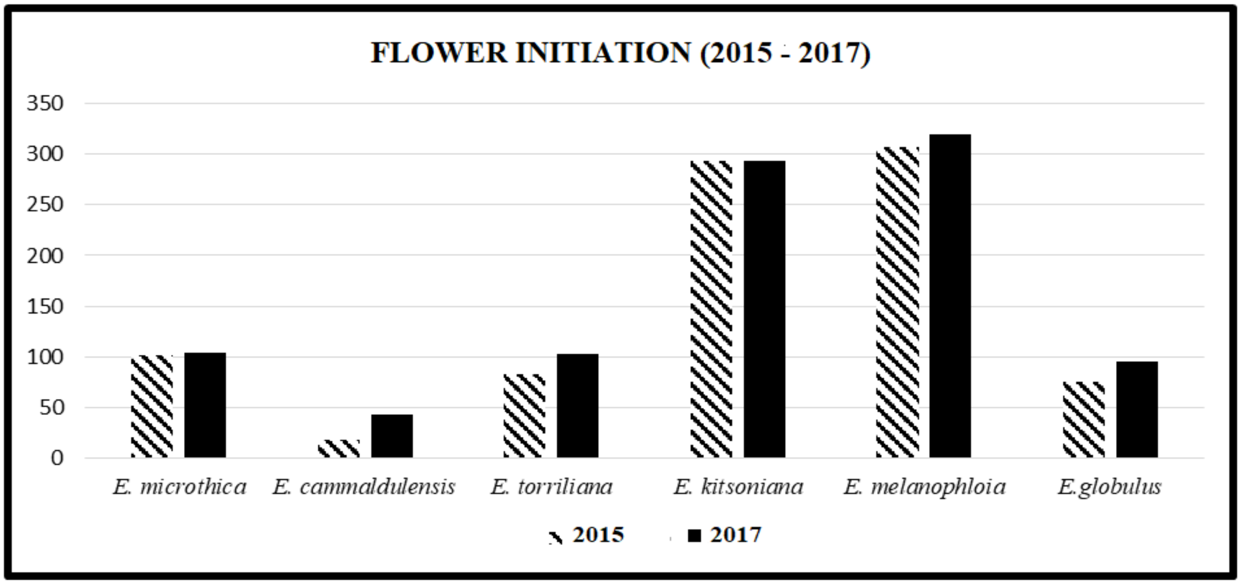

Figure 6. Climate variation and its impact on flower completion in six eucalyptus species for the years 2015 and 2017.

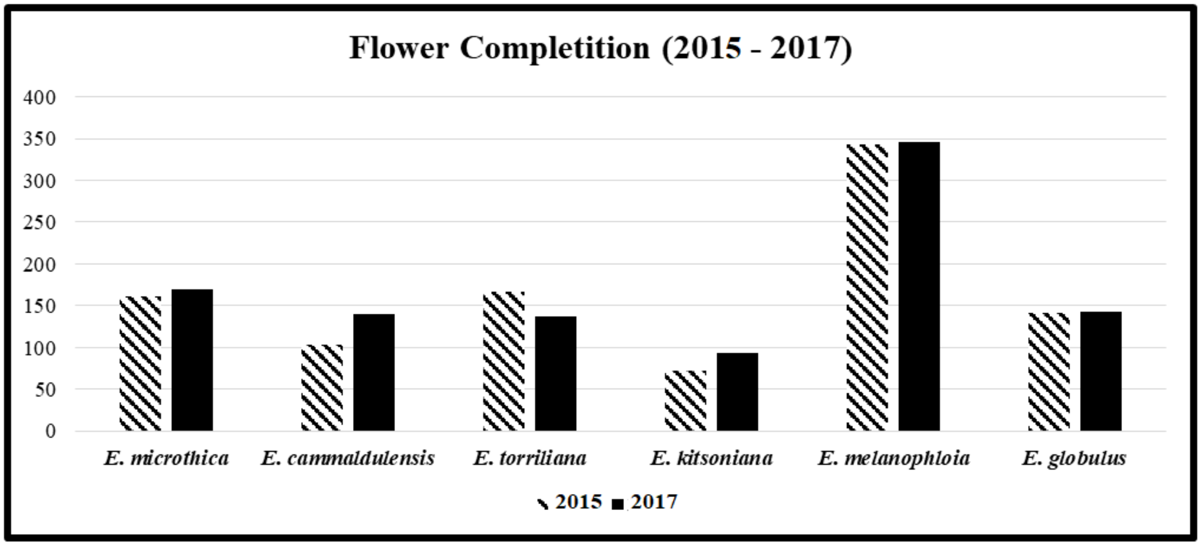

Figure 7. Climate change and its impact on seed production in six eucalyptus species for the years 2015 and 2017.

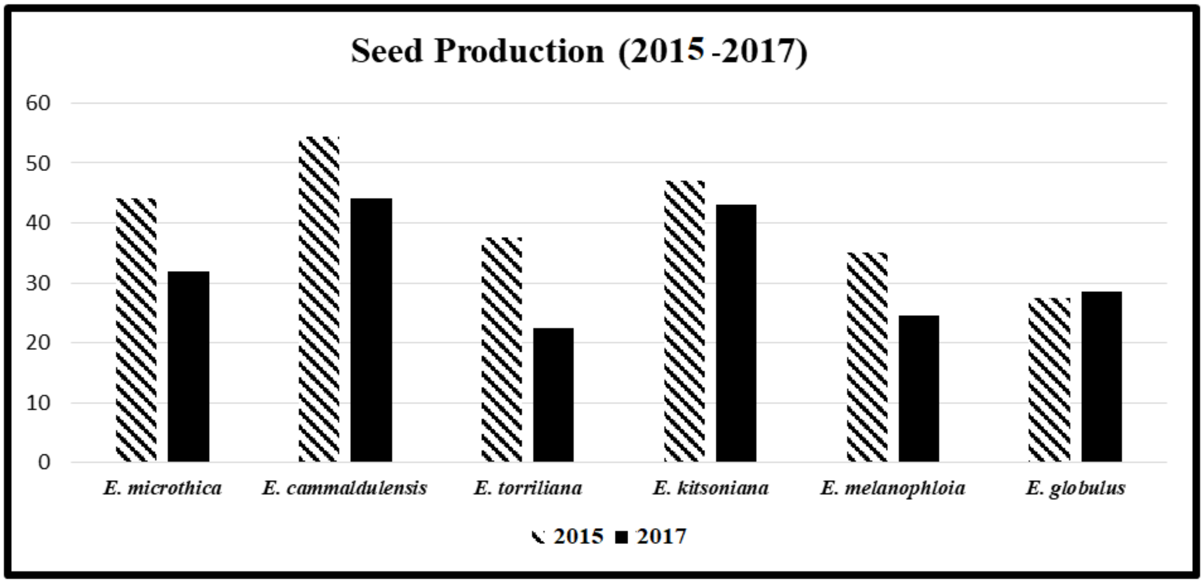

Figure 8. Comparison of seed production in six eucalyptus species under changing climate conditions for the years 2015 and 2017.