Research Article

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Influence of elevation and rainfall on leaf growth, bean characteristics and yield components of arabica and robusta coffee under changing climatic conditions in Karnataka state, India

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Abstract

The study was undertaken to analyze the behaviour of coffee under changing climatic conditions in different coffee liaison zones of Karnataka State, India, during 2017-2020. Sample estates were identified based on elevation and rainfall patterns in different zones of the Chikkamagaluru and Hassan districts. The leaf growth parameters, bean characteristics and yield components were recorded in all the sample estates. Correlation studies indicated a significant positive relationship between the elevation, rainfall with specific leaf area ($r = +0.912$) and productivity ($r = 0.475$) during the pre-monsoon period. The monthly summer rainfall during March and April showed a significant correlation with yield in robusta ($r = 0.511$) and arabica ($r = 0.451$), indicating that blossom shower during this period significantly influenced the productivity of coffee. The studies between elevation, the quantum of rainfall and bean defect parameters indicated a significant ($p<0.05$) positive correlation. A positive relationship was also found between elevation and peaberry production in both robusta ($r = 0.716$) and arabica coffee ($r= 0.456$), respectively. However, there was also a significant relationship between rainfall (2020) and Jollu percentage ($r = 0.386$) in robusta coffee, indicating that higher elevation and rainfall-induced more peaberry content and Jollu percentage under changing climatic conditions. The overall result indicated that changes in climatic conditions such as excess rainfall and continuous soil moisture led to more vegetative growth than reproductive growth. This also produced more bean abnormalities which in turn affected the yield and quality of the coffee.

Keywords: Bean disorders, elevation, leaf growth, rainfall, yield components

Introduction

Climate change is a natural phenomenon, and the biological system has its inherent capacity to adjust to the changes occurring in external environmental conditions. The past century has seen a change in climate conditions at unprecedented levels, with average global warming of 1 ºC since the beginning of the industrial revolution. According to the report of the Inter-Governmental Panel on Climate Change (IPCC) released in 2021, it was concluded that, by the end of the 21st century, global average temperatures would be between 2 ºC and 4 ºC higher, and the sea level may increase to 3.7 cm than pre-industrial levels (Allan *et al.*, 2021). Precipitation changes are also expected to be widespread, intensifying the water cycle and shifts in rainfall patterns. It was also reported that wetlands would increase, and dry lands would face more droughts. Climate change is, therefore, most likely to have a critical effect on the agricultural sector by altering the climatic conditions, affecting the growth and development of the plant.

Coffee is a perennial plant growing under a shade canopy and requires optimum climatic

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Corresponding Author: patil4033@gmail.com conditions for its growth and development. Coffee cultivation in India is confined mostly to hilly tracts of Western and Eastern Ghats, as a well-distributed annual rainfall is preferable (Nagaraj and Kishor, 2020). In general, the area and production of coffee in India are about 4.16 lakh ha and 3.19 lakh MT respectively, with a productivity of 767 kg per ha (Database Coffee Board of India, 2019). Coffee bushes are highly sensitive to changes in adverse climatic conditions such as increased temperature, unpredicted rainfall, heavy wind, and droughts that affect the physiology of coffee plants. Like other crops, coffee also requires optimal weather conditions for its better performance in terms of the growth and development of the plant.

The adverse climatic conditions produce more vegetative growth and higher bean disorders, leading to the reduced physical and intrinsic quality of coffee seeds. Climatic factors like inadequate rainfall patterns, high shade and continuous drought affect the growth and development of coffee (Damatta and Ramalho, 2006). The optimum temperature range for the growth of coffee is 15 to 24 ºC and 24 to 30 ºC with precipitation of 1500 to 2000 mm and 2500 mm per year, respectively, for arabica and robusta coffee (Mitchell, 1988). The rainfall should be well distributed for robusta coffee as the plants are shallow rooted. Climate disturbances have led to fluctuations in yields in almost all the coffee-growing countries.

Baker (1999) of CAB International (www.cabi.org) opines that an increase of 3 ºC in temperature by the end of this century may result in the lower altitude limit for growing good quality arabica coffee, moving higher by 15 feet per year. This will affect millions of producers and all participants in the industry's value chain, the end user, the coffee consumer *etc.,* (Rudragouda *et al.,* 2017). An increase in temperature will force coffee to ripen faster than normal, impacting the inherent quality. An increase in temperature coupled with low rainfall or erratic distribution will affect flowering, fruit set, and berry development (Laderach *et al.,* 2008). Rising temperature is expected to make some areas less suitable or completely unsuitable for coffee cultivation, resulting in an increased incidence of pests and diseases and affecting the quality of coffee produced (Hijmans *et al.,* 2005). Overall, the production cost is expected to increase.

The bean disorder is another physiological problem which occurs mainly due to the depletion of carbohydrate reserves during the developing stages of berries (Gopal *et al.,* 1975). Improper nutrition and adverse climatic conditions, improper bush management, climatic changes like low light intensity at early development stages and other climatic factors like hail stone during the pre-monsoon period followed by soil saturation conditions are reported to increase bean abnormalities in coffee (Mayne, 1938; Cooil and Nakayama, 1953; Janardhan *et al*., 1971). One of these factors alone or in combination affects berry development at various stages due to inadequate dry matter accumulation in the developing berries (Wormer, 1966). Anand *et al*. (2013) reported bean disorder to the tune of 19.4 to 84.8 per cent in arabica coffee grown at lower elevations in North Eastern regions of India. Badru *et al.* (2000) documented seasonal variations in bean disorder formation in non-traditional coffee growing belts.

Hence, the changes in climatic factors like elevation, rainfall pattern and soil moisture content contribute to growth and bean abnormalities in coffee, affecting the out-turn ratio and quality of produce. During the 2017 to 2020 period, coffee-growing regions of Karnataka state witnessed unusual rainfall patterns. Various plantations in different regions reported a low out-turn ratio in both arabica and robusta coffee. Therefore, a study was conducted in different liaison zones of Chikkamagaluru and Hassan to find out the impact of elevation and rainfall patterns on the growth of the plant and bean abnormalities.

Materials and methods

The study was conducted in the Chikkamagaluru and Hassan districts of Karnataka state during 2017-2020. Six zones were selected for the study in Chikkamagaluru (two arabica zones and four robusta zones) and Hassan (three robusta and three arabica zones). The weather parameters such as elevation and rainfall received during the particular period were recorded. The periodical observations on growth parameters such as leaf area, specific leaf area and bean characters like normal beans, half filled, jollu and black bean were also recorded from all the zones. The correlation study was done to know the relationship between the elevation, rainfall on growth parameters, bean disorders and yield components of arabica and robusta coffee.

Correlation studies were conducted to find out the relationship between the quantum of monthly summer rainfall and yield components such as leaves per branch (LPB), nodes per branch (NPB), berries per branch (BPB), berries per cropping nodes (BCN) and cropping nodes per branch (CNB) in arabica and robusta coffee to understand the effect of changing climate on yield performance at these locations. Further, leaf samples were brought to measure specific leaf area and weight. The length and breadth of all the leaves were measured and multiplied with the correction factor for arabica (0.63) and robusta (0.65), as suggested by Awatramani and Gopalakrishna (1965). Specific leaf area (SLA) represented the average leaf expansion in area per unit leaf dry weight and was expressed as $dm^2 g^{-1}$. This was calculated using the formula suggested by Evans and Rasmussen (1972). Specific leaf weight (leaf thickness) represented the average leaf weight per unit leaf area and was expressed as $g\ dm^{-2}$. The dry weight of all the 10 leaves mentioned above was taken after drying in an oven at 50 ºC.

Results and discussion

The results of the study indicated that a significant negative relationship existed between quantum of February rainfall and NPB (r = -0.758), BPB (r = -0.551) and BCN (r = -0.775) as well as March rainfall and NPB (r = -0.588), BCN (r = -0.425) and CNB (r = -0.491). No significant relationship was found between January rainfall and yield components, indicating early summer rainfall from January to March did not influence the yield components in arabica coffee. However, the April rainfall has shown a positive relationship with LPB (r = 0.548), NPB (r = 0.563), BPB (r = 0.451), BCN (r = 0.576) and CNB (r = 0.619) (Table 1). A similar result was confirmed by earlier studies (Busby, 1991) which reported that the rainfall during the early period did not influence yield components of arabica coffee as the extension of growth takes place during the monsoon period.

The yield results on robusta coffee in March summer rainfall has shown a positive relationship with LBP (r = 0.628), NPB (r = 0.900), BPB (r = 0.511), BCN (r = 0.510) and CNB (r = 0.517) unlike arabica coffee. However, the February rainfall has shown a negative response to LPB (r = -0.764), BPB (r = -0.503), and CNB (r = -0.923), indicating early rainfall during February is not useful for robusta coffee (Table 2). These correlation studies indicated that rainfall in March was useful for robusta coffee and rain during April for arabica coffee to improve crop productivity. These results also inferred that a short stress period during the early summer months was useful for arabica coffee compared to robusta coffee to induce better yield components. The berry growth pattern might be due to differences in rainfall pattern, the quantum of rainfall, wet feet conditions, atmospheric temperature and sunshine hours during the monsoon period. The wide variations of growth

Table 1. Correlation matrix between monthly summer rainfall and yield components in arabica coffee

Parameters/ monthly rainfall	Feb	Mar	Apr	May	LPB	NPB	BPB	BCN
Feb	0							
Mar	-0.018	0						
Apr	0.069	-0.952	0					
May	-0.609	-0.233	0.142	0				
LPB	-0.354	-0.094	0.549	0.009	0			
NPB	-0.758	-0.588	0.563	0.434	0.484	0		
BPB	-0.551	-0.330	0.451	-0.060	0.794	0.810	0	
BCN	-0.775	-0.425	0.576	0.373	0.083	0.880	0.596	0
CNB	-0.223	-0.491	0.619	-0.302	0.704	0.676	0.928	0.448

Table 2. Correlation matrix between monthly summer rainfall and yield components in robusta coffee

Parameters/ monthly rainfall	Feb	Mar	Apr	May	LPB	NPB	BPB	BCN
Feb								
Mar	0.065							
Apr	0.069	-0.952						
May	-0.609	-0.233	0.142					
LPB	-0.764	0.628	0.539	0.608				
NPB	-0.229	0.900	0.828	0.631	0.747			
BPB	-0.503	0.511	0.309	0.862	0.734	0.781		
BCN	-0.291	0.510	0.247	0.654	0.589	0.685	0.937	
CNB	-0.923	0.517	0.532	0.605	0.594	0.066	0.548	0.422

trend lines in robusta coffee indicated more vulnerability of robusta coffee to climate changes (Fischer *et al.,* 2002).

Studies on monsoon quantum of monthly rainfall and productivity indicated no significant relationship except quantum of July rainfall. The total quantum of July rainfall has shown a significant positive relationship (r = 0.475) with productivity in arabica coffee (Fig. 1). This could be due to premature berry drop induced by higher rainfall during July (Anand *et al*., 2000). However, no such relationship was observed between monthly monsoon rainfall and the productivity of robusta coffee in the entire zone.

The data were subjected to correlation analysis to understand the influence of elevation and quantum of rainfall on leaf growth traits. The results indicated differences in the behaviour of arabica coffee and robusta coffee with respect to specific leaf area (SLA) and specific leaf weight (SLW) to elevation, average rainfall and previous season's total rainfall (Table 3 & 4). A significant positive relationship was observed between specific leaf area (r = +0.912), elevation (r = +0.592) and average rainfall (r = +0.571) and last year's rainfall in arabica coffee, but such a relationship was not observed in robusta coffee during pre-monsoon period. However, specific leaf weight has shown a negative relationship with elevation (r = -0.522), average rainfall (r = -0.520) and last season rainfall (r = -0.602) in arabica coffee indicating low rainfall increases specific leaf weight. The robusta coffee has shown a negative relationship with specific leaf area and specific leaf weight with average rainfall (r = -0.510) and last season rainfall (r = -0.466). These results indicated that higher rainfall and elevation increase SLA in arabica coffee and are associated with a reduction in SLW. This is due to

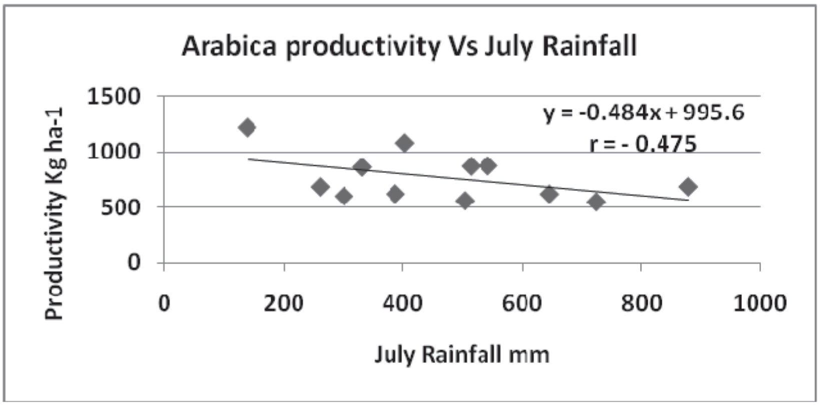

Fig. 1. Correlation and regression analysis between July rainfall and productivity in coffee

Table 3. Correlation analysis between elevations, rainfall, specific leaf area (SLA) and specific leaf weight (SLW) in arabica coffee during monsoon season

Parameters	Elevation	Average rainfall	Rainfall 2017-20	SLA (Pre-monsoon)	SLW (Pre-monsoon)	SLA (Mid monsoon)
Average rainfall	0.123					
Rainfall -2017-20	0.147	0.992				
SLA (Pre-monsoon)	0.912	0.592	0.571			
SLW (Pre-monsoon)	-0.522	-0.520	-0.602	-0.523		
SLA (Mid monsoon)	0.265	0.171	0.148	0.537	0.071	
SLW (Mid monsoon)	-0.479	-0.372	-0.306	-0.456	-0.108	-0.592

Table 4. Correlation analysis between elevation, rainfall, specific leaf area (SLA) and specific leaf weight (SLW) in robusta coffee during monsoon

Parameters	Elevation	Average rainfall	Rainfall 2017-20	SLA (Pre-monsoon)	SLW (Pre-monsoon)	SLA (Mid monsoon)
Average rainfall	-0.143					
Avg RF 2017-20	-0.318	0.953				
SLA (Pre-monsoon)	-0.299	0.237	0.267			
SLW (Pre-monsoon)	-0.001	-0.510	-0.466	-0.469		
SLA (Mid monsoon)	-0.289	-0.384	-0.366	0.300	-0.106	
SLW (Mid monsoon)	0.043	0.326	0.367	0.213	-0.067	-0.735

prolonged winter with high atmospheric temperature and continuous soil moisture resulting in more leaf growth (Rosenthal, 2011). Low rainfall and elevation indicated better leaf growth analysis traits in robusta coffee.

The study indicated that in the Chikkamagaluru district, the total damaged beans was 23.8 per cent in robusta (includes 14.2% half-filled beans, 5.8% jollu and 3.8% black beans) and 21.2 per cent in arabica (includes 11.7% half-filled beans, 5.8% jollu and 3.7% black beans). In contrast, in the Hassan zone, the total damaged beans were 26.4 per cent (including 19% half-filled beans, 5.1% jollu and 2.3% black beans); in robusta and arabica coffee, the total damaged beans were 22.7 per cent which included 15.3 per cent of half-filled beans, 5.5 per cent of jollu and 1.8 per cent of black beans in 45 collected samples (Fig. 2). However, in normal years, the bean disorders ranged between 2 to 5 per cent.

Correlation studies to understand the relationships between elevation, rainfall and bean

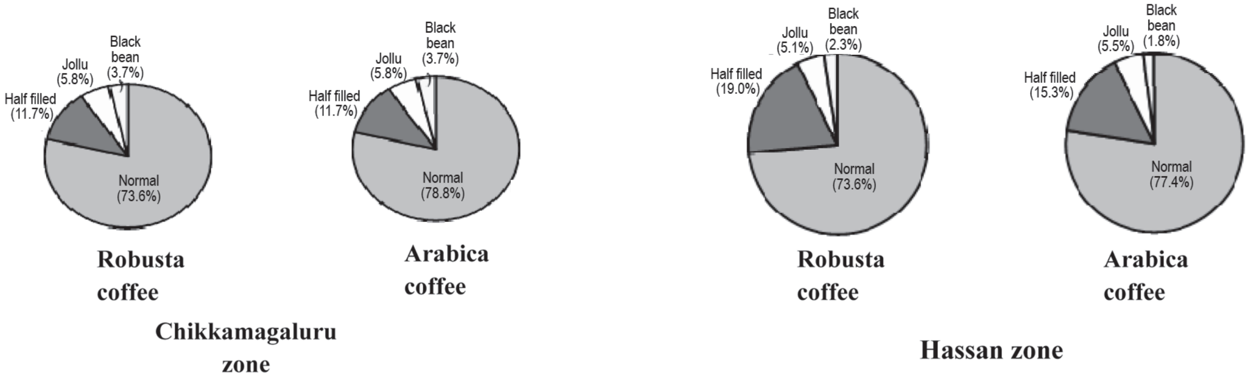

Fig. 2. Studies on bean abnormalities in Chikkamagaluru and Hassan zones

Table 5. Correlation matrix between elevation, rainfall and bean abnormalities of robusta coffee in the Chikkamagaluru zone

Parameters	Elevation	Average rainfall	Rainfall 2020	Normal	Peaberry	Half locule	Triage
Ave. rainfall	-0.186						
Rainfall 2020	-0.355	0.985					
Normal	-0.382	-0.110	-0.128				
Peaberry	0.456	-0.102	-0.010	-0.846			
Half locule	-0.150	0.164	0.167	-0.318	0.043		
Triage	0.382	-0.232	-0.213	-0.397	0.235	0.355	
Jollu	0.042	0.386	0.279	-0.415	0.176	-0.146	-0.240

Table 6. Correlation matrix between elevation, rainfall and bean abnormalities of arabica coffee in the Chikkamagaluru zone

Parameters	Elevation	Average rainfall	Rainfall 2020	Normal	Peaberry	Half locule	Triage
Ave. rainfall	0.792						
Rainfall 2020	0.625	0.916					
Normal	-0.215	-0.321	-0.287				
Peaberry	0.716	0.296	0.318	-0.345			
Half locule	-0.543	-0.386	-0.211	0.267	-0.010		
Triage	0.367	-0.095	-0.263	-0.212	0.513	0.087	
Jollu	0.286	-0.063	-0.121	-0.586	-0.421	-0.573	-0.316

abnormalities indicated a significant positive relationship between the quantum of rainfall and bean defect parameters (r = 0.456) and (r = 0.716) between elevation and peaberry production and also elevation and jollu per cent (r = 0.042 & r = 0.286) in both robusta and arabica coffee respectively indicating higher elevation induces more peaberry content (Cooil and Nakayama, 1953) and more jollu percentage under changing climatic conditions in Chikkamagaluru zone. The higher the rainfall, the lower the bean filling and continuous precipitation produced more jollu in robusta coffee. The continuous soil moisture during the early bean filling stage after blossoming produces more peaberries (Hagger and Kathleen, 2012). In robusta coffee, a positive relationship was observed between average rainfall, rainfall (2020) and jollu percentage (r = 0.386) and (r = 0.279) and similarly in half locule (r = 0.164 and r = 0.167) percentage indicating higher rainfall also induces more of bean disorders (Table 5). In arabica coffee, a positive relationship (r = 0.296 and r = 0.318) was observed between peaberry content, average rainfall, rainfall (2020) (Table 6). This implied a negative influence of elevation and high rainfall on the out-turn of arabica coffee.

Conclusion

Coffee plants are sensitive to changes in climatic conditions. The rainfall and elevation play a major role in the growth and development of coffee. The timely occurrence of summer showers will be useful for robusta and arabica coffee to improve crop productivity. Shifts in the showers lead to floral abnormalities. Continuous soil moisture stress could be responsible for reducing plant carbohydrate status. Continuous soil saturation during the berry development stage produced more peaberries, premature berry drop during monsoon time due to wet feet and bean abnormalities due to reduced translocation of carbohydrates from leaves to developing berries. Therefore, it is important to take initiatives to reduce the impact of climate change on coffee production by practising suggested agronomical technologies to cope with the seemingly inevitable effects.

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