Biological Forum – An International Journal **14(4): 394-403(2022)**

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Genotype-environment Interactions in Nutmeg (*Myristica fragrans* Houtt.)

S.C. Priyanka[1*], N. Miniraj[2], P. Lincydavis[3] and H.C. Vikram[4]
[1]Ph.D. Scholar, Department of Plantation Crops and Spices,
College of Agriculture, Kerala Agricultural University, Thrissur (Kerala), India.
[2]Retd. Professor, Department of Plantation Crops and Spices,
College of Agriculture, Kerala Agricultural University, Thrissur (Kerala), India.
[3]Assistant Professor, Department of Agricultural Meteorology,
College of Agriculture, Kerala Agricultural University, Thrissur (Kerala), India.
[4]Assistant Professor, Department of Plantation Crops and Spices,
College of Agriculture, Kerala Agricultural University, Thrissur (Kerala), India.

(Corresponding author: S.C. Priyanka)*
(Received 29 August 2022, Accepted 08 October, 2022)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Nutmeg (*Myristica fragrans* Houtt.) is a climate-sensitive perennial spice crop. There are several elite genotypes available in nutmeg which exhibit differential performance at various locations, due to their interactions with the environment. Very less information is available on genotype-environment interactions in nutmeg, which has got a long pre-bearing period. The present study was conducted with dual objectives of examining the performance of a set of nutmeg genotypes across diverse locations and their response to weather parameters with a view to identify genotype-specific adaptation as well as wide adaptability. Six genotypes of nutmeg which include three nutmeg varieties released from KAU, two promising farmer varieties and national check (IISR Vishwasree) were purposively selected for the study. For each genotype, three locations were chosen based on altitude. Six weather variables considered for the study were maximum temperature, minimum temperature, relative humidity, rainfall, wind speed and sunshine hours. To work out the linear relationship between yield traits (nut as well as mace yield per tree) and weather variables, Pearson's correlation analyses were done followed by stepwise regression. The flowering phase ranged from 31st to the 44th standard meteorological week. The duration of each phenophase varied among the genotypes as well as locations. The weather variables which exerted positive influence on yield were, wind speed and rainfall in KAU Mundathanam (85.5%); maximum temperature in KAU Pullan (40.1%); relative humidity in Kadukammakkal (26.3%). In KAU Kochukudy, it was sunshine hours that influenced the dry nut yield per tree (62.6%) positively whereas it was minimum temperature that exerted a negative influence on dry mace yield per tree (69.0%). The illumination factor, sunshine hours negatively influenced all the yield traits in IISR Vishwasree (81.6%) and Kinattukara (47.2%). Highly significant differential response of nutmeg genotypes with weather was evident from all the locations. The magnitude of influence of weather variables for the yield traits was significantly different and specific to genotype. The study could indicate the suitability of each genotype in the studied locations.

Keywords: Nutmeg (*Myristica fragrans* Houtt.), nut yield per tree, mace yield per tree, wind speed, rainfall, sunshine hours.

INTRODUCTION

Nutmeg (*Myristica fragrans* Houtt.) is an evergreen aromatic tree spice, a highly remunerative spice of trade in domestic as well as global markets. India's current area under cultivation of nutmeg is rising steadily with 24,080 ha and production of 15,384 tonnes (Spices board, 2022). Kerala still holds the pioneer position in the area (22,875 ha) and production (14,589 tonnes) of nutmeg (Spices board, 2022). The spice crop production in Kerala is subjected to the vagaries of weather. But literature are scanty to understand the effect of climate variability. For better growth and yield in any crop, favourable weather variables are a prerequisite. Every species of plant behaves differently in their response to the environment (Moss, 1976; Thomas, 1993). Each genotype interacts with climatic variables, and a differential performance is always expected rather than the same when a genotype has been selected in one environment and cultivated in another (Maulion *et al.,* 2014). Rubber clone's performance varied spatially and fluctuated between years within a location (Meenakumari *et al.,* 2011). Biophysical factors such as rainfall and temperature may act synergistically or antagonistically with other factors in determining yield and quality (Melke and Fetene 2014). For example, blossom and backing summer showers are crucial for good yield in coffee, but these pre-monsoon showers adversely affect black pepper's flowering and fruit setting phase (Gopakumar, 2011). Rainfall pattern over the state of Kerala shows a declining trend in South West monsoon rainfall and an increasing trend in post monsoon rainfall in the past 50 to 60 years (Krishnakumar *et al.,* 2009). Present pattern of shifting rainfall and high-intensity downpours could adversely affect most of the spice crops, as they are grown in ecologically sensitive hilly areas, areas with high rainfall and high humidity. This highlights the needfulness to conduct studies on the relationships between crop genotypes and weather variables on their growth and development. Nutmeg is a climate-sensitive crop; high humidity and distributed rainfall with well-drained fertile soil are ideal conditions required for its growth. Nutmeg, being a cross-pollinated crop due to its dioecious nature, gets assisted by wind and insect pollination (Thangaselvabai *et al.,* 2011). Climate determines the intensity and availability of pollinating agents, which ultimately result in fruit set and yield. Adverse climatic conditions like higher wind intensity and frequent torrential precipitation can lead to uprooting and root rotting in nutmeg, as they are shallow-rooted. Being perennial in nature, tree spices like nutmeg, have to face the impact of climate change even during a single generation or in a standing plantation itself.

In perennial crops, genotype environment interaction is a major challenge faced by plant breeders in selecting and recommending the superior genotype with best yield performance and also wider adaptability over different locations. The present study was conducted with the dual objectives of examining the performance of a set of nutmeg genotypes across diverse locations and their response to weather parameters with a view to identify genotype-specific adaptation as well as wide adaptability. An understanding of the extent of influence of weather fluctuations at critical phenophases of growth of various nutmeg genotypes and their performance in terms of economic yield under different agro climatic conditions are crucial for selecting the best performing genotypes for various locations.

MATERIALS AND METHODS

The study was conducted during 2018-2020 at the Department of Plantation Crops and Spices, College of Agriculture, Kerala Agricultural University, Thrissur. Five nutmeg genotypes were selected for the study which included three high-yielding nutmeg varieties from Kerala Agricultural University (KAU Mundathanam, KAU Kochukudy, KAU Pullan); two promising farmer varieties, Kadukammakkal and Kinattukara, featuring good yield and the national check variety (IISR Vishwasree). Farmer's holdings having healthy population of these genotypes were purposively selected. A minimum of three locations were identified for each of the genotypes based on altitude. In each location, three budded trees of the same age group (6-8 yrs) per genotype were selected. The nutmeg genotypes used in the study and their detailed location information are given in Table 1. Six weather variables considered for the study were maximum temperature, minimum temperature, relative humidity, rainfall, wind speed and sunshine hours. The agro-meteorological data from each study location were recorded for two consecutive years. Yield parameters were also recorded at peak bearing season from the selected nutmeg trees for two years. Yield traits considered were nut yield per tree and mace yield per tree. Weather variables along with yield and yield components were utilised to assess the genotype weather relationships. To work out the linear relationship between yield and weather variables, Pearson's correlation analyses were done at four distinct phenophases of the tree.

Table 1: List of nutmeg genotypes used in the study and their locations.

Sr. No.	Variety	Nutmeg trees	District	Location	Latitude (°N)	Altitude (m)
1.	KAU PULLAN	PNC-1, PNC-2, PNC-3	Thrissur	Chalakudy	10.32	10
		PNA-1, PNA-2, PNA-3	Alappuzha	Poochakkal	9.80	8
		PNU-1, PNU-2	Ernakulam	Udayamperoor	9.91	4
2.	KAU KOCHUKUDY	KCJ-1, KCJ-2, KCJ-3	Ernakulam	Kallurkadu	9.98	14
		KCK-1, KCK-2, KCK-3	Malappuram	Karuvarakund	11.15	82
		KCY-1, KCY-2, KCY-3	Palakkad	Palakuzhy	10.50	425
3.	KAU MUNDATHANAM	MNY-1, MNY-2,MNY-3	Palakkad	Palakuzhy	10.5	428
		MNP-1, MNP-2,MNP-3	Kottayam	Previthanam	9.74	42
		MNU-1, MNU-2, MNU-3	Kottayam	Ullanadu	9.75	40
4.	KADUKKAMAKKAL	KDK-1, KDK-2, KDK-3	Malappuram	Karuvarakund	11.16	88
		KDY-1, KDY-2, KDY-3	Palakkad	Palakuzhy	10.53	402
		KDN-1, KDN-2, KDN-3	Thrissur	Nadathara	10.51	16
5.	KINNATTUKARA	KNK-1, KNK-2, KNK-3	Malappuram	Karuvarakund	11.15	81
		KNU-1, KNU-2, KNU-3	Ernakulam	Udayamperoor	9.91	6
		KNZ-1, KNZ-2, KNZ-3	Idukki	Kanjikuzhi	9.93	691
6.	IISR VISWASREE	VSU-1, VSU-2, VSU-3	Ernakulam	Udayamperoor	9.91	5
		VSP-1, VSP-2	Palakkad	Palakuzhy	10.50	421
		VSK-1	Ernakulam	Kallurkadu	9.98	25

Table 2: Correlation between weather parameters and yield attributes in fruit development cum maturation phase of growth in nutmeg.

P3 PHENOPHASE	Weather variables					
NUT YIELD PER TREE	T_{max}	T_{min}	RH	WS	RF	SS
KAU Mundathanam	0.831**	0.844**	-0.735**	0.909**	-0.676**	-0.825**
KAU Kochukudy	-0.749**	-0.781**	0.580*	-0.740**	0.627**	0.791**
KAU Pullan	0.726**	-0.660**	-0.582*	0.075	-0.396	-0.38
Kadukammakkal	-0.357	0.146	0.509*	0.07	0.391	-0.508*
Kinnatukkara	-0.362	-0.586*	0.513*	-0.516*	0.672**	-0.796**
IISR Viswasree	0.192	-0.254	-0.022	-0.078	0.132	-0.896**
MACE YIELD PER TREE	T_{max}	T_{min}	RH	WS	RF	SS
KAU Mundathanam	0.707**	0.713**	-0.650**	0.802**	-0.532*	-0.679**
KAU Kochukudy	-0.776**	-0.830**	0.550*	-0.775**	0.672**	0.800**
KAU Pullan	0.633**	-0.598**	-0.384	0.075	-0.335	-0.454
Kadukammakkal	-0.414	0.056	0.516*	-0.025	0.433	-0.499*
Kinnatukkara	-0.13	-0.552*	0.181	-0.414	0.432	-0.558*
IISR Viswasree	0.325	-0.162	-0.201	0.035	0.001	-0.847**

T_{max}- Maximum temperature, T_{min}- Minimum temperature, RH- Relative humidity, WS-Wind speed, RF-rainfall and SS-Sunshine hours

Among the four phenophases, fruit development cum maturation phase was pivotal, with regard to yield contributing factors in all genotypes and the correlation table obtained is given in Table 2. The weather variables that expressed significant correlation with nutmeg yield in the third phenophase were selected to fit the stepwise regression model. Stepwise regression with annual yield as the response variable and the selected weather variables as independent variables was done to determine the most significant meteorological variable influencing nutmeg yield in each location during the study period.

RESULTS AND DISCUSSION

Fixing the growth phenophases in nutmeg. In order to understand the influence of weather parameters on various phases of nutmeg growth, a phenological calendar was prepared based on the observations recorded from the trees across the locations. Four distinct phenophases *i.e.* flushing phase (P1), flowering phase (P2), fruit development cum maturity phase (P3) and fruit harvest phase (P4) could be observed. The duration of each phenophase varied among the genotypes as well as locations. Each of the genotype and phenophase was plotted against standard meteorological weeks, as given in Fig. 1. Irrespective of the genotypes, the flowering phase ranged from 31st to the 44th standard meteorological week. Flower bud initiation started immediately after the cessation of monsoon rains, in all the genotypes. In KAU Pullan, the flowering commenced from 34th week (August 2nd fortnight) at Poochakal (9°80′N, 8m altitude), whereas at Udayamperoor (9°91′N, 4m altitude) and Chalakudy (10°32′N, 10m altitude) the flowering commenced from 36th week (September 1st fortnight). In KAU Kochukudy at Kallurkadu (9°98′N, 14m altitude), the flowering commenced from 38th week (September 2nd fortnight), whereas at Karuvarakund (11°15′N, 82m altitude) flowering was seen from 36th week (September 1st fortnight) and at high ranges like Palakuzhy (10° 50′N, 425m altitude) the flowering was a bit late and commenced from 40th week (October 1st fortnight). In KAU Mundathanam, the flowering started from 36th week (September 1st fortnight) at Ullanad (9° 75′N, 40m altitude) and Previthanam (9° 74′N, 42m altitude), but delayed commencement in flowering was noticed at Palakuzhy (10° 50′N, 428m altitude) from 40th week (October 1st fortnight). However, the flowering pattern noticed in Kadukammakkal genotype was slightly early from 31st week (August 1st fortnight) at Nadathara (10° 51′N, 16m altitude) and 33rd week (August 2nd fortnight) at Karuvarakund (11° 16′N, 88m altitude), but at Palakuzhy (10° 53′N, 402m altitude) the flowering commenced late by 37th week (September 2nd fortnight). In Kinattukara genotype at Udayamperoor (9° 91′N, 6m altitude), the flowering commenced from 38th week (September 2nd fortnight), whereas at Karuvarakund (11°15’N, 81m altitude) flowering was seen from 31st week (August 1st fortnight) and at high ranges like Kanjikuzhi (9° 93′N, 691m altitude) the flowering commenced from 36th week (September first fortnight). In IISR Vishwasree, the flowering phase started from 38th week (September 2nd fortnight) at Kallurkadu (9° 98′N, 25m altitude) and Palakuzhy (10° 50′N, 421m altitude). However, at Udayamperoor (9° 91′N, 5m altitude) the flowering was seen from 40th week (October 1st fortnight). Nazeem (1979) has reported six flushes in nutmeg, however in the present study only four flushes could be observed. In general, irrespective of the genotypes, at lower elevations flowering was early starting in early August whereas it went up to mid-October at higher elevations. Among the genotypes also there was variation in the initiation of flowering. These results indicate that commencement of flowering varies from location to location based on latitudinal and altitudinal differences, and is in accordance with Hopkin’s bioclimatic law. Hopkins (1938) revealed the importance of latitude, longitude and altitude in the distribution and pace of development of plants by means of a “Bioclimatic law”. Bioclimatic law stated that “A biotic event in North America will, in general, show a lag of four days for each degree of latitude, five degrees of longitude and 400 ft of altitude, northwards, eastward and upward in spring and early summer”. Similarly in 1957, Indian Meteorological Department stated that delay in mango flowering from South to North of India also was in accordance to Hopkin’s bioclimatic law. Weather plays an important role in spring blooming fruit crops due to combined effects on bee activity, flower opening, pollen germination and fertilization (Tuell and Issacs 2010). Singh *et al*. (1998), reported that in mango, each genotype needs certain amounts of accumulation of heat units for completion of different phenophases which cause the variation in flowering and maturity period. Ausin *et al*. (2005), were of the opinion that high temperature may promote early anthesis with small reproductive structures, and can also induce flower abortion rarely while low temperature caused a delay in flowering time. (Sangadji *et al*., 2015) also reported about climatic variables determining the success of fruit set in nutmeg.

Among the four phenophases of growth in nutmeg, the fruit development cum maturation phase (P3) is the most crucial irrespective of the genotypes. It was also the longest phenophase among the four. The P3 phase varied approximately from 36th to 22nd standard meteorological weeks, and the phase duration differed for each genotype.

Influence of weather variables over yield attributes of nutmeg genotypes. Nut and mace are the two economic products obtained from the tree. Among the yield contributing parameters, dry nut yield per tree and dry mace yield per tree were selected for further analysis, based on their significance in association studies to fit into a regression model (Table 3) and the results are presented below.

Table 3: Yield prediction models for dry nut yield and mace yield per tree in P3 phenophase of growth in nutmeg.

Sr. No.	Genotypes	Nut yield per tree (dry)	R^2
1	KAU Mundathanam	Y= -4.674+5.494 WS+0.004 RF	0.910
2	KAU Kochukudy	Y=-84.137+4.411 SS	0.626
3	KAU Pullan	Y= -68.869+2.337 Tmax	0.401
4	Kadukammakkal	Y= -23.013+0.372 RH	0.259
5	Kinattukara	Y=66.126-2.972 SS	0.633
6	IISR Vishwasree	Y=38.070-1.806 SS	0.845
	Genotypes	**Mace yield per tree (dry)**	**R^2**
1	KAU Mundathanam	Y= -1.355+1.316 WS+0.001 RF	0.801
2	KAU Kochukudy	Y= 6.224-0.223 Tmin	0.690
3	KAU Pullan	Y= -9.424+ 0.320 Tmax	0.401
4	Kadukammakkal	Y=-6.242 +0.100 RH	0.267
5	Kinattukara	Y= 14.978-0.660 SS	0.311
6	IISR Vishwasree	Y=7.672-0.364 SS	0.787

(i) Nut yield per tree. Interaction of the genotypes with the weather parameters varied across the locations with respect to the nut yield per tree. In KAU Mundathanam genotype, wind speed and temperature exerted a significant positive association with dry nut yield per tree (7.68 kg/tree), whereas a significant negative correlation existed with relative humidity, rainfall, and sunshine hours. But a trend opposite to this was expressed with dry nut yield per tree (5.01 kg /tree) by climate variables for KAU Kochukudy. In KAU Pullan genotype, a significant positive correlation was expressed between the maximum temperature and dry nut yield per tree (6.38 kg/tree), whereas minimum temperature and relative humidity showed a highly negative association with this trait. In Kadukkammakkal, the relative humidity was positively and significantly correlated with dry nut yield per tree (3.68 kg /tree), and a negative association was seen for the duration of sunshine hours. In Kinattukara, a significant positive correlation existed between dry nut yield per tree (6.15 kg/ tree) and weather variables like relative humidity and rainfall whereas the minimum temperature, wind speed and sunshine hours expressed strong negative correlation. In IISR Vishwasree, no significant correlation was obtained for weather variables except the duration of sunshine hours which was found to be of strongly negative association giving a nut yield of 1.37 kg/ tree).

Analysing the differential response of nutmeg genotypes to weather variables and locations, for dry nut yield per tree, KAU Mundathanam and KAU Pullan performed better, irrespective of year and location, giving a nut yield of 7.68 kg and 6.38 kg per tree respectively when compared to other genotypes.

The significantly correlated meteorological variables influencing nut yield per tree was further subjected to regression analysis to determine the most significant variable influencing nutmeg yield in each location during the study period. The regression coefficient (R^2) value near to one is more desirable and value greater than 0.5 is considered significant to understand the influence of environment on the genotype. Out of six genotypes studied, four genotypes *viz.,* KAU Mundathanam, KAU Kochukudy, Kinattukara and IISR Vishwasree had R^2value greater than 0.5. A graph was plotted for the prediction model in each genotype for actual and predicted yields as depicted in Fig. 2(a) to 7(a). The significant contribution of rainfall and wind speed to the variation in yield accounts for 91 per cent in KAU Mundathanam genotype, (Y= -4.674+5.494 WS+0.004 RF (R^2 =0.910). This clearly supports that out of six weather variables considered, only two weather variables significantly contributed towards the yield attributes, irrespective of location. In KAU Kochukudy, the regression analyses showed positive influence of duration of sunshine hours on dry nut yield per tree (62.6 %), whereas in Kinattukara genotype, negative influence of sunshine hours was noticed over the yield trait (63.3%). The respective predicted yield in KAU Kochukudy was Y=-84.137+4.411SS and that of Kinattukara genotype was Y=66.126-2.972 SS. In IISR Vishwasree, 84.5 per cent of the variation in dry nut yield per tree could be explained by sunshine hours alone with an inverse relationship. The regression equation obtained is predicted yield Y=38.070-1.806SS (R^2 =0.845).

The regression coefficient was less than 0.6 in KAU Pullan and Kadukammakkal genotypes. The maximum temperature alone could explain 40 per cent of the nut yield per tree in KAU Pullan, while the relative humidity could explain only 25.9 per cent variation in this yield trait.

(ii) Mace yield per tree. Influence of weather parameters on mace yield of nutmeg per tree is discussed here. Agrometeorological factors like wind speed, maximum temperature, and lowest temperature exhibited a definite positive trend with dry mace yield per tree (1.84 kg/tree) in KAU Mundathanam whereas rainfall, relative humidity, and sunshine hours significantly and negatively impacted the dry mace yield per tree. Like nut yield per tree, in KAU Kochukudy genotype, the amount of precipitation, relative humidity and sunshine hours had a considerable positive impact for mace yield per tree (1.10kg/tree). However, there was strong adverse link with temperature, and wind speed. In KAU Pullan, the maximum temperature was significantly positively linked with mace yield per tree (0.88 kg/tree) whereas the minimum temperature exhibited inverse association. The Kadukkammakkal genotype showed a strong negative link between dry mace yield per tree (0.96 kg/tree) and sunshine hours, while a significant positive correlation existed with relative humidity. Furthermore, there was significant adverse correlation between the duration of sunshine hours and minimum temperature with the dry mace yield per tree (1.65 kg/tree) in Kinattukara genotype. However, in IISR Vishwasree, the weather variables had no synergistic or antagonistic relationship with mace yield per tree (0.26 kg/tree) except for sunshine hours which exerted a negative influence.

Like in dry nut yield per tree, differential performance of nutmeg genotypes to weather and location for dry mace yield per tree, indicated that the genotypes KAU Mundathanam (1.84 kg per tree) and Kinattukara (1.65 kg per tree) outperformed, when compared to other genotypes, irrespective of year and location.

In the regression analysis, the genotype's actual and expected yields were plotted on a graph as given in Fig. 2 (b) to 7(b). For mace yield per tree, only three genotypes *viz*., KAU Mundathanam, KAU Kochukudy and IISR Vishwasree show R^2 value greater than 0.5. In KAU Mundathanam, 80.1 per cent of the variation in mace yield per tree could be explained by rainfall and wind speed. The regression equation for KAU Mundathanam was Y= -1.355+1.316 WS+0.001 RF (R^2 = 0.801). This again endorses that rest of the weather variables did not affect much the yield trait irrespective of location. The superiority of KAU Mundathanam in its adaptability to the environmental factors is also evident. Sunshine alone could account inversely for 78.7 % of the fluctuation in mace yield per tree in IISR Vishwasree with forecasted yield, Y=7.672-0.364 SS. In KAU Kochukudy genotype, minimum temperature had negative influence on the mace yield per tree with a contribution of 69%.

Only 40% of the mace yield variability in KAU Pullan could be explained by maximum temperature, where the expected mace yield per tree is Y= -9.424+ 0.320 Tmax (R^2 =0.401). Weather variables except maximum temperature were non-significant. The predicted yield for the Kinattukara genotype is Y=14.978-0.660 SS (R^2 =0.311), duration of sunshine hours alone negatively affected the fluctuations in mace yield per tree which accounts only for 31.1% and rest of weather variables had nonsignificant association with yield trait. In Kadukammakkal, where the regression equation derived was Y= -6.242+0.100 RH (R^2 = 0.267), the contribution of relative humidity on mace yield per tree is only 26.7%.

Influence of climatic variables on perennial crops have been reported by various workers. Agriculturally cultivated plants benefit differently from the temperature in each growth period. Climate indexing studies in nutmeg by Basir *et al*. (2018) revealed that growing degree days, maximum temperature and humidity index were strongly correlated to the productivity of nutmeg plants with correlation coefficient (r) > 0.95. According to Sangadji *et al.* (2015) who carried out climate correlation studies in nutmeg at Indonesia, parameters *viz.,* high rainfall, rainy days, and high humidity lowers the fruit set, while air temperature and solar radiation increase the fruit set. In Indonesia, the contribution of rainfall to the production of nutmeg accounted for 55.12 per cent and air temperature alone contributed 45.52 per cent to the production of nutmeg in Saparua island (Rehatta *et al.,* 2021). In the present study, highly significant differential response of nutmeg genotypes with weather was evident from all the locations. The magnitude of influence of weather variables for the yield traits was significantly different and was specific to genotype. The weather parameters wind speed and rainfall significantly influenced both the yield attributes like nut yield per tree (91%) and mace yield per tree (80%) in KAU Mundathanam According to Rai *et al*. (2003), growing degree days in mango varied significantly due to varied maturity period of different cultivars and ranged from 1660.38 °C in Mithua cultivar to 3222.25° C Kataki cultivar. Clonal variations in response to prevailing climatic conditions have been reported in rubber also (Priyadarshan *et al.,* 2003; Gireesh *et al.,* 2011). Genotype-environment interaction studies in mango carried out by Krishna *et al*. (2022), revealed that Mallika was a stable genotype under unfavourable environmental conditions while Totapari and Vanraj genotype were suitable for cultivation under favourable conditions.

Sushna (2016) observed that high temperature and sunshine hours during March stimulated the production of more number of spikes in black pepper grown in high ranges. But at the same time, rainfall and humidity during March hindered the dry spell effect and caused reduction in pepper yield. Spatial variability of daily diffused and direct light transmitted to shoots was very high within the tree in peach (Genard and Baret 1994) which again contributed to variation in yield. Likewise in KAU Kochukudy, only sunshine hours positively influenced the dry nut yield per tree (62.6%), whereas the dry mace yield per tree (69%) was negatively influenced by the minimum temperature. However, in KAU Pullan maximum temperature alone positively influenced the variation in all the yield attributes with relatively lower regression coefficient. Also, high temperature inhibited the photosynthesis and enhanced respiration loss, which caused hastened leaf senescence, thereby reducing the yield in coconut (Kumar and Aggarwal 2013). It was relative humidity that positively affected the dry nut and mace yield per tree in Kadukkammakkal. Sunshine hours alone showed significant negative effect on the fluctuations in all the yield attributes in Kinattukara genotype. In Vishwasree, the contribution of sunshine hours on all the yield traits considered was negatively significant. In their analyses on genotype environment interactions on rubber yield, Meenakumari *et al.* (2011) identified clones with wider adaptability as well as specific adaptation. RRIM 600 was found to be the widely adapted rubber clone. Among the weather parameters, maximum temperature was negatively correlated with yield in Kanyakumari, one of the traditional rubber producing zone, irrespective of clones.

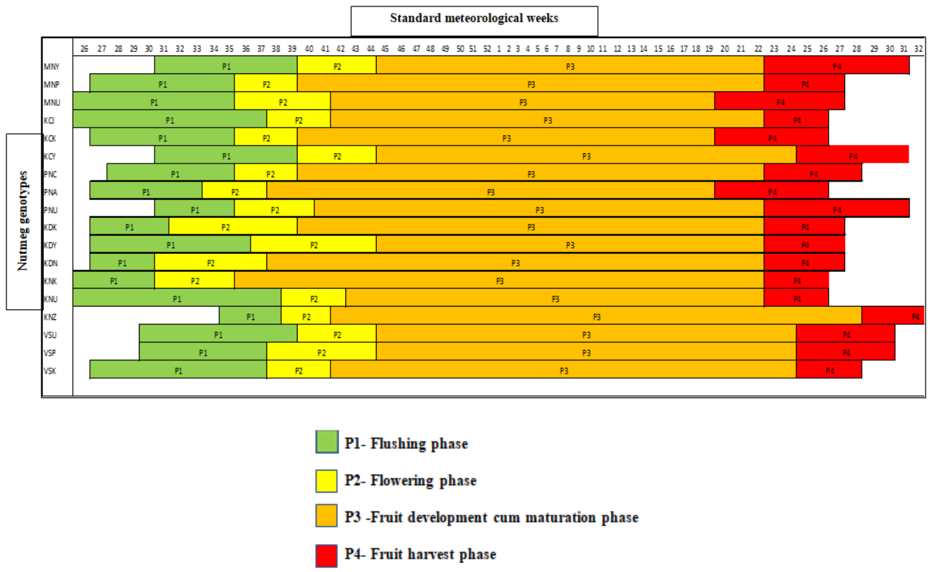

Fig. 1. Spatio-temporal variations in growth phenophases of nutmeg genotypes.

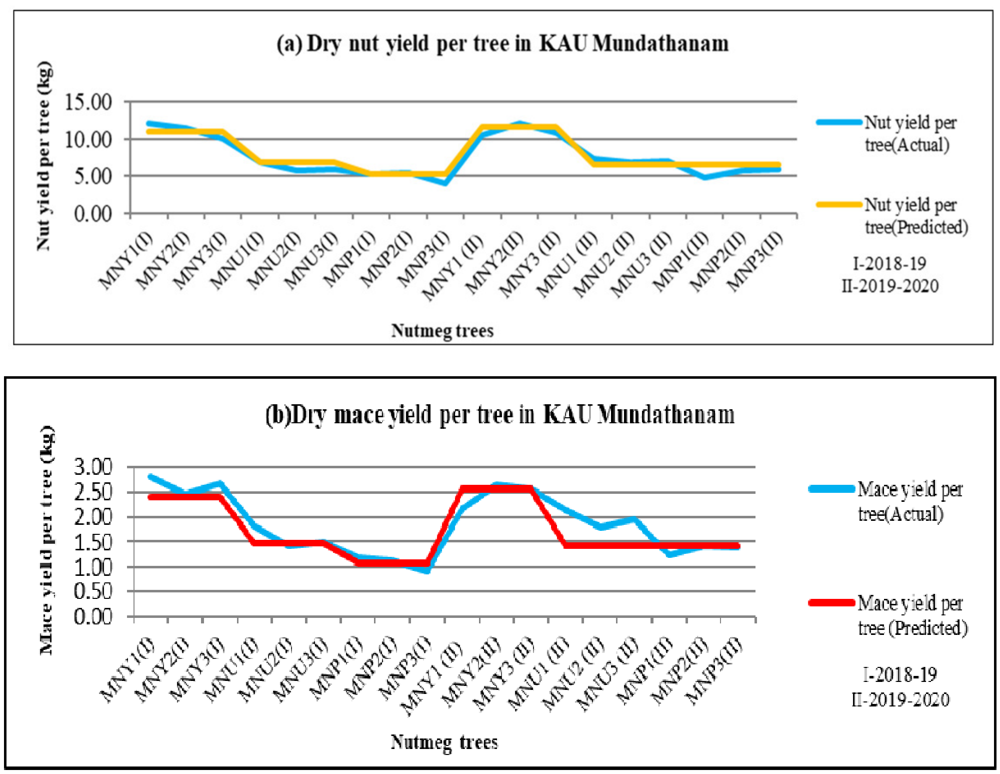

Fig. 2 (a) and (b) Comparison between actual and predicted yield attributes in KAU Mundathanam.

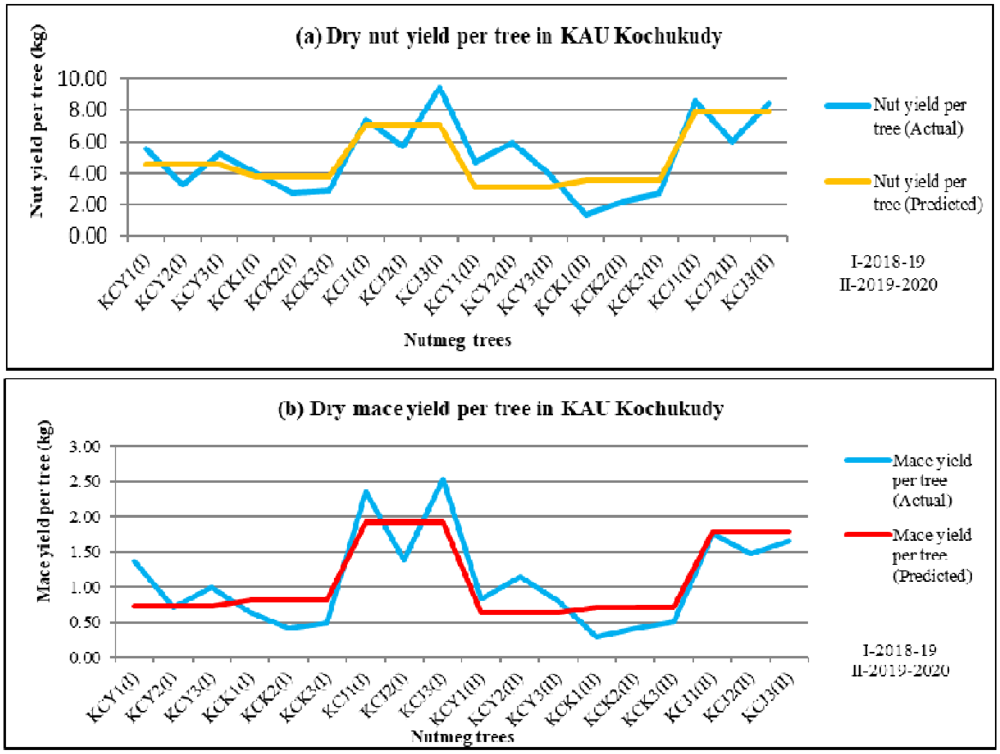

Fig. 3 (a) and (b) Comparison between actual and predicted yield attributes in KAU Kochukudy.

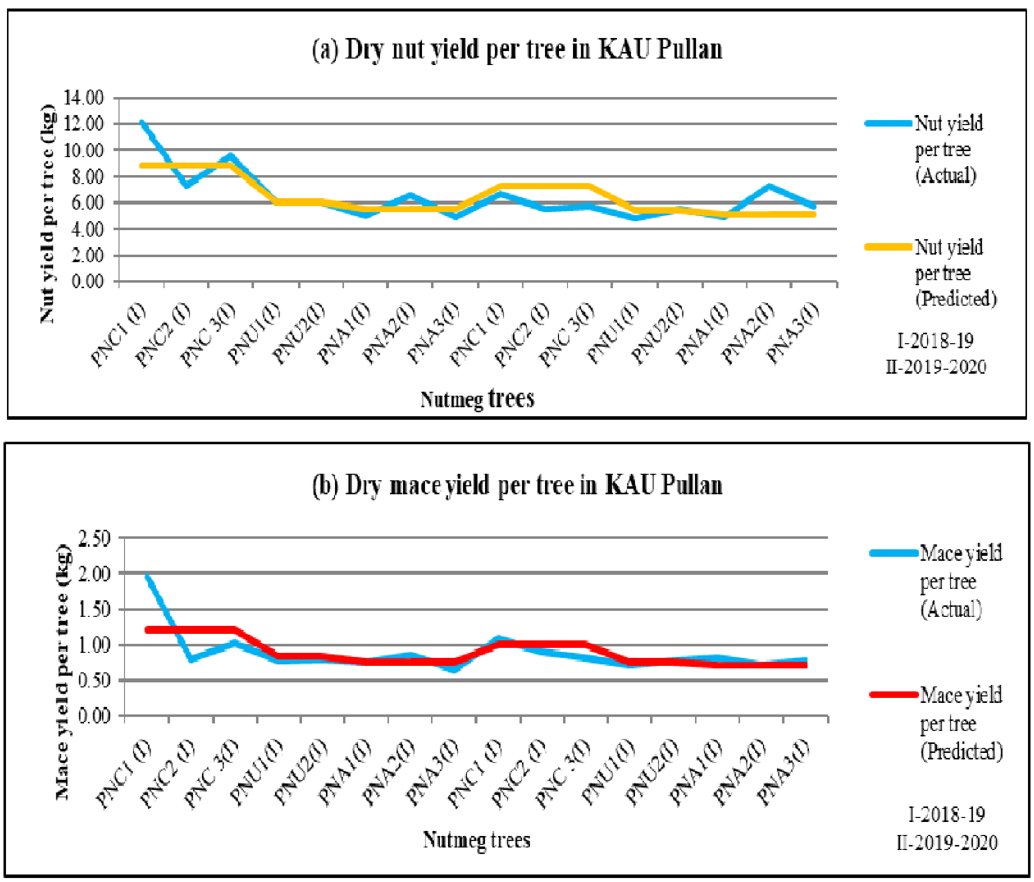

Fig. 4 (a) and (b) Comparison between actual and predicted yield attributes in KAU Pullan.

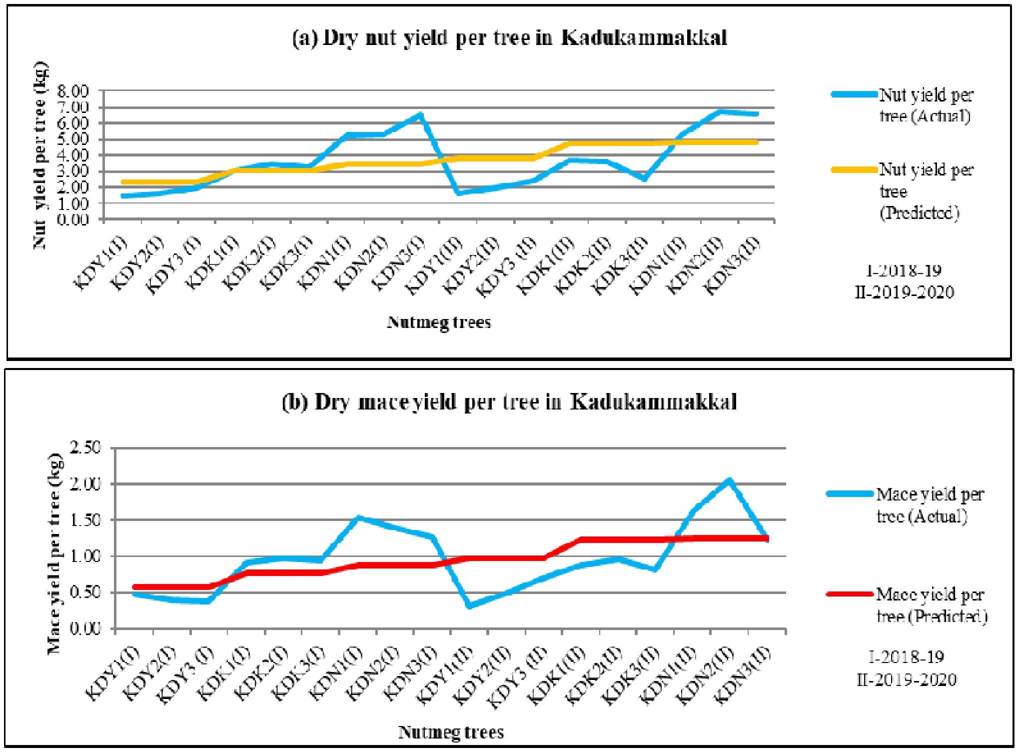

Fig. 5 (a) and (b) Comparison between actual and predicted yield attributes in Kadukammakkal.

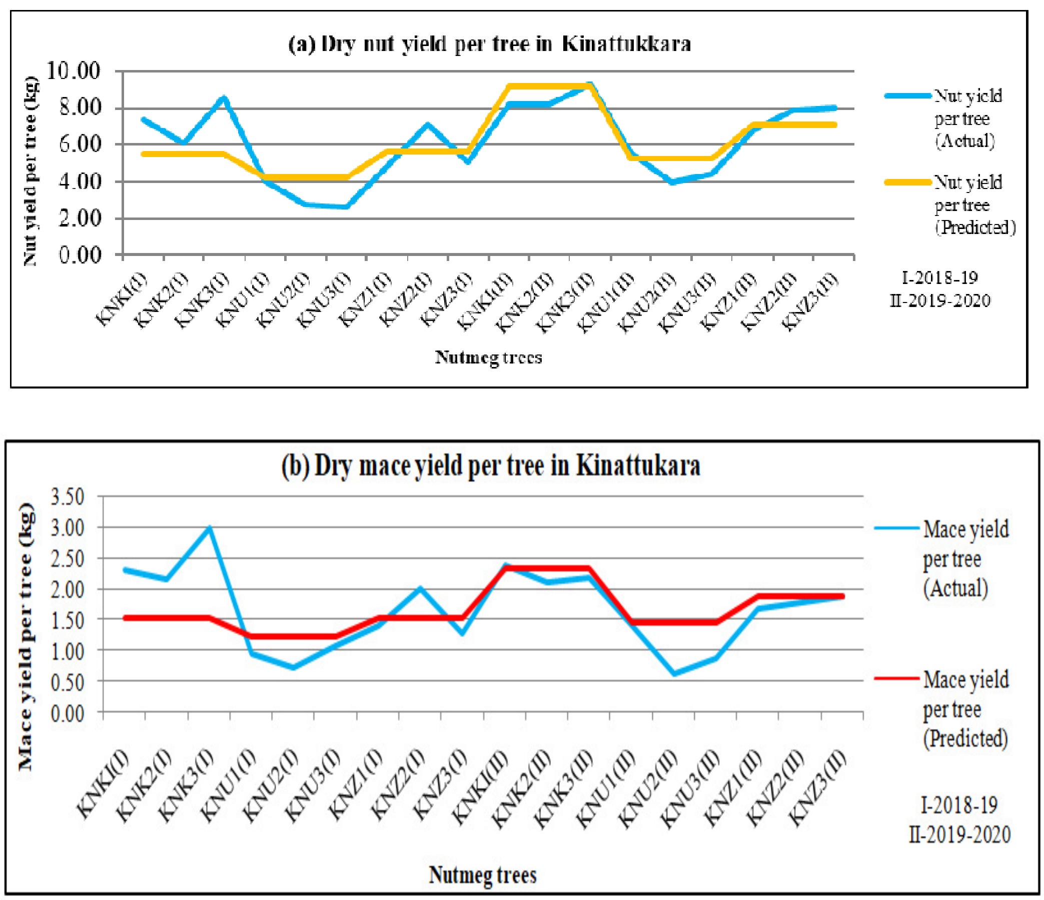

Fig. 6 (a) and (b) Comparison of actual and predicted yield attributes in Kinattukara.

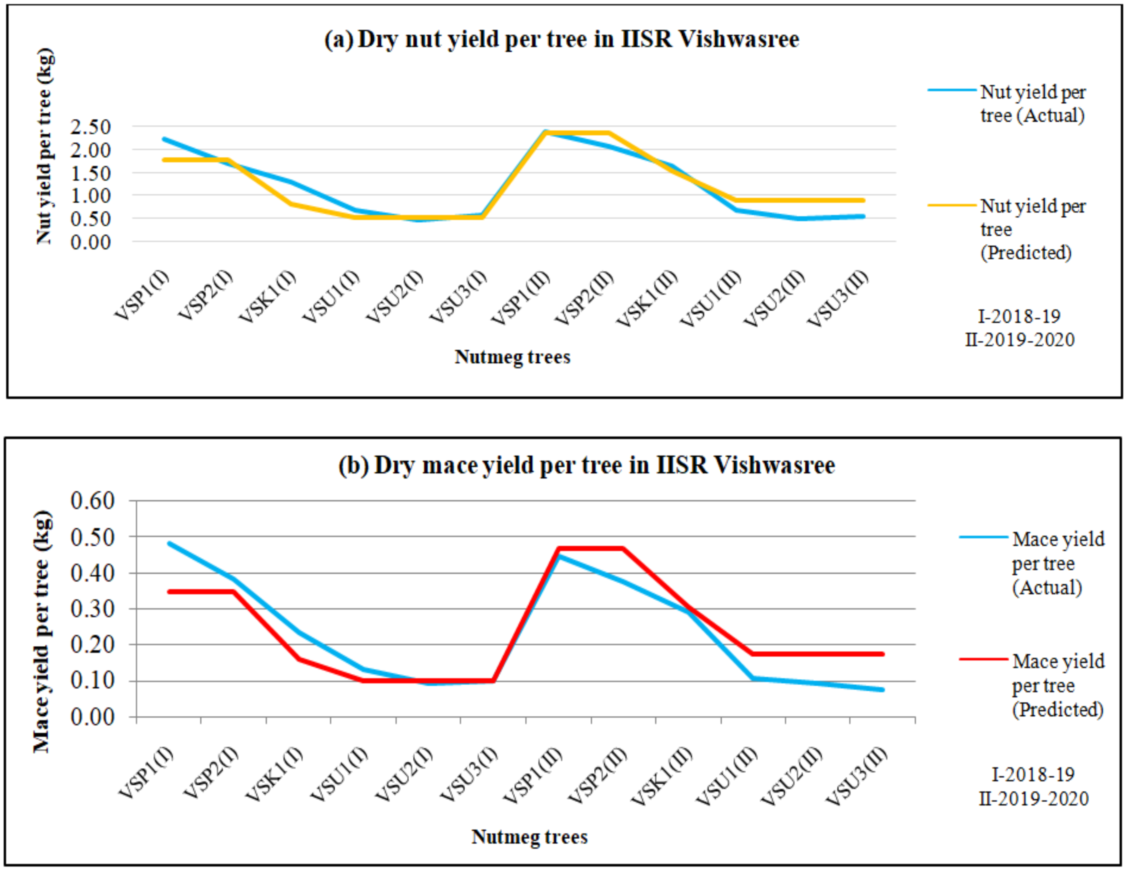

Fig. 7 (a) and (b) Comparison of actual and predicted yield attributes in IISR Vishwasree.

CONCLUSION

It is important to understand the influence of weather variables in perennial crops like nutmeg. The environments were diverse and there were sizeable differences in the response of genotypes to environments. Among the four phenophases of growth in nutmeg, the fruit development cum maturation phase (P3) is highly crucial with respect to the yield contributing factors in all genotypes. The duration of each phenophase varied among the genotypes as well as locations. Significant variation among genotypes, locations, and for genotype by location interactions with weather variables was observed for the two yield attributes. Considering the genotype-environment influences across the locations, the regression coefficient R^2 value for KAU Mundathanam was quite high combined with highest nut and mace yield per tree. The weather variables which exerted positive influence on yield were, wind speed and rainfall in KAU Mundathanam (85.5%); maximum temperature in KAU Pullan (40.1%); relative humidity in Kadukammakkal (26.3%). Sunshine hours showed a positive influence on dry nut yield per tree (62.6%) in KAU Kochukudy whereas minimum temperature showed a negative influence on dry mace yield per tree (69.0%). The illumination factor, sunshine hours negatively influenced all the yield traits in IISR Vishwasree (81.6%) and Kinattukara (47.2%). The check genotype IISR Vishwasree was the lowest yielder across the locations, and remained unaffected by majority of weather variables.

FUTURE SCOPE

Influence of genotype-environment interactions of various nutmeg genotypes as emerged from the present study could define the suitability of each genotype in the studied location. The increasing demand for nutmeg the world over has necessitated increasing its production through expansion of area or increasing the productivity of the crop. To this end all the nutmeg-producing countries have extended cultivation to non-traditional areas experiencing various biotic and abiotic stresses. This makes the task of the nutmeg breeder difficult in selecting suitable genotypes for areas hitherto unexplored or identifying high-yielding and stable clones showing consistent performance throughout the bearing period. Several high-yielding varieties in nutmeg have been released by various research organisations. If they could be planted in the ideal environments in accordance with the findings from the present study, the production potential of these varieties can be achieved in full.

Acknowledgement. I extend my sincere thanks to major advisor Dr. N. Miniraj and my advisory committee members Dr. P. Lincydavis and Dr. H. C. Vikram for valuable suggestions and proper guidance throughout the course of study. The authors are thankful to Kerala Agricultural University, Thrissur, Kerala for the support and financial assistance to undertake the study.

Conflict of interest: None.

REFERENCES

Ausin, I., Blanco, C. A. and Zapater, J. M. M. (2005). Environmental regulation of flowering. *International Journal of Developmental Biology*, *49*(5): 689-705.

Basir, A., Neswati, R., Baja, S. and Lopulisa, C. (2018). Climate index for estimating nutmeg plant suitability under tropical rainforests in Maluku Province, Indonesia. *International Journal of Agriculture and Environmental Science*, *5*(6): 23-30.

Genard, M. and Baret, F. (1994). Spatial and temporal variation of light inside peach trees. *Journal of the American Society for Horticultural Science*, *119*(4): 669-677.

Gireesh, T., Raj, S., Mydin, K. K. and Mercykutty, V. C. (2011). Rubber yield of certain clones of *Hevea brasiliensis* and its relationship with climate variables. *Indian Journal of Natural Rubber Research*, *24*(1): 54-60.

Gopakumar, C. S., Prasada Rao, G. S. L. H. V. and Ram Mohan, H. S. (2011). *Impacts of climate variability on agriculture in Kerala*. Doctoral dissertation, Cochin University of Science & Technology. 250pp

Hopkins, A. D. (1938). *Bioclimatics: A science of life and climate relations*. United States Department of Agriculture, Miscellaneous Publication No. 280. United States Department of Agriculture, Washington, D.C., USA.

Krishna, K. S., Chaudhary, R. K. and Kumar, M. (2022). Analysis of genotype x environment interaction and identification of superior mango (*Mangifera indica* L) genotypes using Eberhart and Russell's stability model. *Biological Forum- An International Journal, 14*(1): 1502-1505.

Krishnakumar, K. N., Rao, G. P. and Gopakumar, C. S. (2009). Rainfall trends in twentieth century over Kerala, India. *Atmospheric Environment*, *43*(11): 1940-1944.

Kumar, S. N. and Aggarwal, P. K. (2013). Climate change and coconut plantations in India: Impacts and potential adaptation gains. *Agricultural Systems*, *117*: 45-54.

Maulion, E., Valentini, G., Ornella, L., Pairoba, C. F., Daorden, M. E. and Cervigni, G. D. L. (2014). Study of statistic stability to select high-yielding and stable peach genotypes. *Scientia Horticulturae*, *175*: 258-268.

Meenakumari, T., Meenattoor, J. R., Soman, T. A., Dey, S. K., Das, G., Raj, S., Sailajadevi, T., Nair, R. B., Raman, A., Gireesh, T. and Mydin, K. K. (2011). Yield of modern Hevea clones and their response to weather parameters across diverse environments. *Natural Rubber Research*, *24*(1): 44-53.

Melke, A. and Fetene, M. (2014). Apples (*Malus domestica*, Borkh.) phenology in Ethiopian Highlands: Plant growth, blooming, fruit development and fruit quality perspectives. *American Journal of Experimental Agriculture*, *4*(12): 1958.

Moss, G. I. (1976). Temperature effects on flower initiation in sweet orange (*Citrus sinensis*). *Australian Journal of Agricultural Research*, *27*(3): 399-407.

Nazeem, P. A. (1979). Studies on growth, flowering, fruit set and fruit development in nutmeg. MSc. (Hort.) Thesis Kerala Agricultural University, Thrissur, p.136.

Priyadarshan, P. M. (2003). Contributions of weather variables for specific adaptation of rubber tree (Hevea brasiliensis Muell.-Arg) clones. *Genetics and molecular biology*, *26*: 435-440.

Rai, M., Nath, V., Das, B. and Rai A. (2003). Growing Degree Days requirement of mango cultivars for maturity under sub humid plateau region of eastern India. *The Orissa Journal of Horticulture*, *31*(2): 13-17.

Rehatta, H., Leatemia, J. A. and Laimeheriwa, S. (2021). The impact of climate variables on nutmeg (Mirystica fragrans HOUTT) production in Saparua Island, Central Maluku Regency. In: *IOP Conference Series: Earth and Environmental Science*, IOP Publishing Ltd 797(1): 012025.

Sangadji, S., kaimuddin, Ala, A. and Paembonan, S. A. (2015). The effect of climate to the fruit set of nutmeg plant. *International Journal of Current Research and Academic Review*, 3(8): 352-358.

Singh, R. S., Vashishtha, B. B. and Prasad, R. N. (1998). Micrometeorology of ber (*Zizyphus mauritiana*) orchard grown under rainfed arid conditions. *Indian Journal of Horticulture*, *55*(2): 97-107.

Spices Board (2022). Spice wise area and Production. Available at http://www.indianspices.com. [08 September 2022].

Sushna, K. (2016). Influence of weather parameters on growth and yield of black pepper (*Piper nigrum* L.). M.Sc. (Agri.) Thesis, Kerala Agricultural University, Thrissur, p. 103.

Thangaselvabai, T., Sudha, K. R., Selvakumar, T. and Balakumbahan, R. (2011). Nutmeg (*Myristica fragrans* Houtt)-the twin spice-a review. *Agricultural Reviews*, *32*(4): 283-293.

Thomas, B. (1993). Internal and external controls on flowering. *The molecular biology of flowering.*, *46*:1-19.

Tuell, J. K. and Isaacs, R. (2010). Weather during bloom affects pollination and yield of highbush blueberry. *Journal of Economic Entomology*, *103*(3): 557-562.

How to cite this article: S.C. Priyanka, N. Miniraj, P. Lincydavis and H.C. Vikram (2022). Genotype-environment Interactions in Nutmeg (*Myristica fragrans* Houtt.). *Biological Forum – An International Journal, 14*(4): 394-403.