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Diversity of airborne mycofloral abundance and allergenic fungal spores of Enugu North, Nigeria

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Abstract Airborne mycofloral spores are important part of the fungal inocula responsible for various infections, decays and allergies in the environment. Unfortunately, the diversity, abundance and rhythm of seasonal occurrence are poorly known and studied in this part of the tropics. The aims of this study were to ascertain the airborne fungal spore diversity and their monthly and seasonal abundance at the different locations. The influence of some meteorological factors on 18 most abundant and fungal spore genera was under studied. The study was conducted in Enugu North using modified Tauber Traps at locations differing in urbanization for a period of 12 months. The results showed that 49 airborne fungal spore genera were identified which varied in abundance across the seasons, months and locations. The highest airborne fungal spore abundance and diversity were recorded during the rainy season, and the majority of the airborne spore genera had their peak frequencies in October, July and March. The highest spore abundance was recorded in Adani, but majority of the spore diversity had their maximum frequency of occurrence at Enugu Ezike and Adani. High fungal spore diversity and abundance were recorded more in higher-altitude locations, especially the most frequent and abundant airborne fungal spore genera such as *Nigrospora, Endophragmiella, Ustilago, Botryodiplodia, Pithomyces* and *Venturia*. Statistically, there were significant differences ($p < 0.05$) in the abundance of airborne fungal spores at both the locations and months. Spearman's correlation analysis showed that the abundance of spore genera of *Cladosporium, Alternaria, Endophragmiella, Torula, Uromyces* and *Venturia* had significant ($p < 0.05$) correlation relationship with meteorological factors.

Keywords Airborne fungal diversity · Meteorological factors · Fungal spore abundance · Enugu North

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1 Introduction

Airborne fungal spores constitute important proportion of atmospheric particles of biological origin (Adhikari et al. 2004; Ataygul et al. 2007), varying tremendously in form, size and diversity. Despite the cosmopolitan nature, variations still exist in the diversity and abundance of the spores across different climatic regions and phytoecological zones. This can be attributed to the rate of fungal spore release and dispersal in the atmosphere which depends on a complex interaction of biological and environmental variables such as meteorological conditions, host vegetation, harvest seasons, sporulation rhythms of different fungi and anthropogenic activities

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(Sabariego et al. 2000; Okten et al. 2005; Grinn-Gofron and Bosiacka 2015). Spore types of different taxa such as the smuts, rusts and mitosporic fungi are often abundant in the air during periods of low humidity and high temperature and hence are artificial grouped as dry-air spores, whereas many ascospores and basidiospores which are released during or immediately after rainfall are regarded as wet-air spores (Jedryczka 2014).

In fact, the period of release of spores may be directly related to the ease of their establishment on new hosts. This may possibly explain why numerous ascospores and basidiospores of pathogenic fungi are wet-air spores. High humidity and/or wet environment appears to be a precondition for their effective infection of host plants. Seasonal variations in airborne fungal spores have been reported by many authors (Rodriguez-Rajo et al. 2005; Grinn-Gofron 2008; Hossain and Pasha 2012). Spores of different fungi have been reported to show specific diurnal and seasonal cycles which are influenced by climate, weather conditions, circadian timing and availability of substrates needed for growth and development of the fungus (Calderon et al. 1995). That is why abundant fungal spores are recorded in the summer in temperate regions (Kasprzyk and Worek 2006), whereas in tropical regions the spores occur in large quantities during the rainy/wet seasons (Hasnain 1993; Njokuocha et al. 2017).

Although most fungal spores are dispersed by air movement, the distance to which they travel depends on many variables such as spore size and form, wind velocity, temperature, source height and extent of air turbulence (Jedryczka 2014). Spore dispersal is seen as biological survival mechanism that enables movement of spores to new areas, serves as inocula to fungal infections and spreads to new host as well as a means of survival of adverse environmental conditions (Jedryczka 2014), while the abundance and distribution of airborne fungal spores are variably affected by meteorological factors (Burch and Levetin 2002; Hernandez-Trejo et al. 2012; Grinn-Gofron et al. 2017). Some other studies have attributed airborne spore abundance to the interactive effects of meteorological factors which impacts greater influence on the release and abundance of spores of many fungi in the atmosphere (Adhikari et al. 2004; Troutt and Levetin 2001). Rainfall, relative humidity, temperature and wind velocity have been widely reported as among the foremost meteorological factors that affect the growth, sporulation, release, distribution and abundance of fungal spores in the atmosphere (Burch and Levetin 2002; Stepalska and Wolek 2005; Damialis and Gioulekas 2006; Ianovici et al. 2013).

Airborne fungal spores have been associated with the spread of human, animal and plant diseases (Huang et al. 2010; McNeil and Palazzi 2012). Spore types of specific fungal taxa have been reported to be implicated in allergic symptoms such as skin, eyes and nasal irritations and respiratory diseases such as asthma and alveolitis (Meri et al. 2003; Bush and Prochnau 2004; Gioulekas et al. 2004; Jedryczka 2014). Others like *Aspergillus* are associated with nosocomial infections of immunocompromised patients. They have also been reported to cause plant diseases some of which have resulted in massive crop failure, poor yield, postharvest losses of crops, deterioration of stored food and household materials (Kahmann et al. 2000; Pernezny et al. 2003; Rodriguez-Rajo et al. 2005; Toth et al. 2007; Wright et al. 2008; Plummer and Templeton 2011). Therefore, good knowledge of the circulation of these airborne spores will help in early detection of new pathogenic species, devising an efficient and quick intervention method of curbing disease outbreaks in plants, improving annual crop yield through correct timing planting as well as application of appropriate fungicides.

In Nigeria, concerted efforts have been made to identify airborne fungal spores (Agwu and Osibe 1992; Agwu et al. 2004: Njokuocha and Osayi 2005; Njokuocha and Agwu 2007; Essien et al. 2013; Aliyu and Gambo 2014) circulating in the atmosphere of the different regions. Previous studies have shown that spore taxa recorded in most places are similar to those reported for other parts of the world with the spore members of the Ascomycotina dominating the air spora (Chakraborty et al. 2001; Agwu et al. 2004; Njokuocha and Osayi 2005; Li et al. 2010). However, differences exist in the most dominant spore types. While *Cladosporium* and *Alternaria* spore types have been reported as the most abundant fungi genera present in the atmosphere of most countries of the temperate region (Sakiyan and Inceoglu 2003; Rodriguez-Rajo et al. 2005; Jedryczka 2014), they have not been recorded in such high abundance in related studies in Nigeria. Rather *Nigrospora, Endophragmiella, Ustilago, Botryodiplodia* and *Curvularia* have remained comparatively higher (Agwu et al. 2004;

Njokuocha and Agwu 2007; Essien et al. 2013; Njokuocha et al. 2017).

These airborne fungal spores constitute potential health hazards to the human population and agricultural crops. Therefore, good knowledge of this airborne fungal spore diversity will help in proper clinical diagnosis and immunotherapy, early detection of new pathogenic species, devising an efficient and quick intervention method of curbing disease outbreaks in plants, improving annual crop yield through correct timing of planting as well as application of appropriate fungicide. It will also contribute to the knowledge and assessment of taxonomic diversity of tropical fungi which at present is poorly studied.

The study was aimed at investigating the airborne fungal spore floral richness, their abundance, seasonal variation and the impact of meteorological factors on their abundance.

2 Study areas

Seven locations were selected for the study, and they are situated within fast growing urban, semi-urban and rural areas in four Local Government Areas of Enugu North senatorial zone (Fig. 1, Table 1). Present in these areas are educational institutions, private and government establishments and open markets that attract large population that are constantly exposed to these airborne fungal spores. Vegetation distribution and level of urbanization informed the study locations. Enugu State is situated in the humid tropical climate with mean annual rainfall varying from 786 to 2098.2 mm. The average monthly air temperature oscillates between 24 and 29 °C. The wind system is influenced by the north-east trades that accentuate the dry season and introduces the cool, dry harmattan weather from the Sahara around early November to late January and may extend up to February, and the SW monsoon which is responsible for rainfall from May to October (rainy season). The climate is therefore influenced the relative position of the Intertropical Convergence Zone (ITCZ) that determines the rainy season (May–October) and the dry season (November–April).

Generally, the vegetation of Enugu State belongs to the mosaic lowland rainforest and secondary grassland, sometimes called derived savanna. An increase in human activities, especially agricultural practices, has led to the fragmentation of the vegetation into different sub-types (Agwu 1997). The vegetation around Adani is fragmented into riparian forests along Adada River channels, oil palm bush land, wooded shrub grassland and open farmland of rice fields as well as mixed cropping of *Manihot esculenta, Zea mays, Abelmoscus esculentus, Capsicum annum, Musa sapientum* and *Musa paradisciaca*. In Ibagwa, the vegetation is predominantly a mosaic farmlands and open woodland shrub grassland with *Elaeis guineensis*, *Parkia biglobosa*, *Daniellia oliveri, Hymenocadia acida, Dialum guineense, Vitex doniana* and *Prosopis africana* among others dominating the tree species. In and around the Botanical Garden and University of Nigeria, Nsukka Campus (UNN II), are aesthetic/horticultural plants and indigenous plants of ecological significance, some of which are relics of the original forest–savanna woodland vegetation of the area.

In Enugu Ezike, the natural woodland vegetation has been converted in some parts into farmlands and mosaic of oil palm bushlands. Growing around the area are indigenous and exotic trees species such as *Daniellia oliveri, Parkia biglobosa, Anthocleista vogeli, Gmelina arborea, Bombax buonopozense, Ceiba pentandra, Irvingia gabonensis* and *Gliricidia sepium.* The vegetation in Orba site consists of farmlands, oil palm forests and remnants of the original woodland flora scattered in patches in the area. The vegetation in Imilike is similar to that in Orba only that some areas of the woodland vegetation and relic forests in Imilike are less disturbed by human activities as well as stretches of swamp and riparian forests along the river channels in the area.

3 Materials and methods

The study was conducted in seven locations (Adani village, Ibagwa, Enugu Ezike, Botanic Garden, University of Nigeria, Nsukka Campus–UNN II, Orba and Imilike) (Table 1, Fig. 1) in Enugu North Senatorial zone, over a period of 12 months (March 2005 to February 2006). The samplers were located in the study areas, and the selection of sampling sites was influenced by the urban, semi-urban and rural nature of the study area. The sampling instruments were modified Tauber pollen traps, non-volumetric static samplers mounted at height of 5 cm at strategic locations

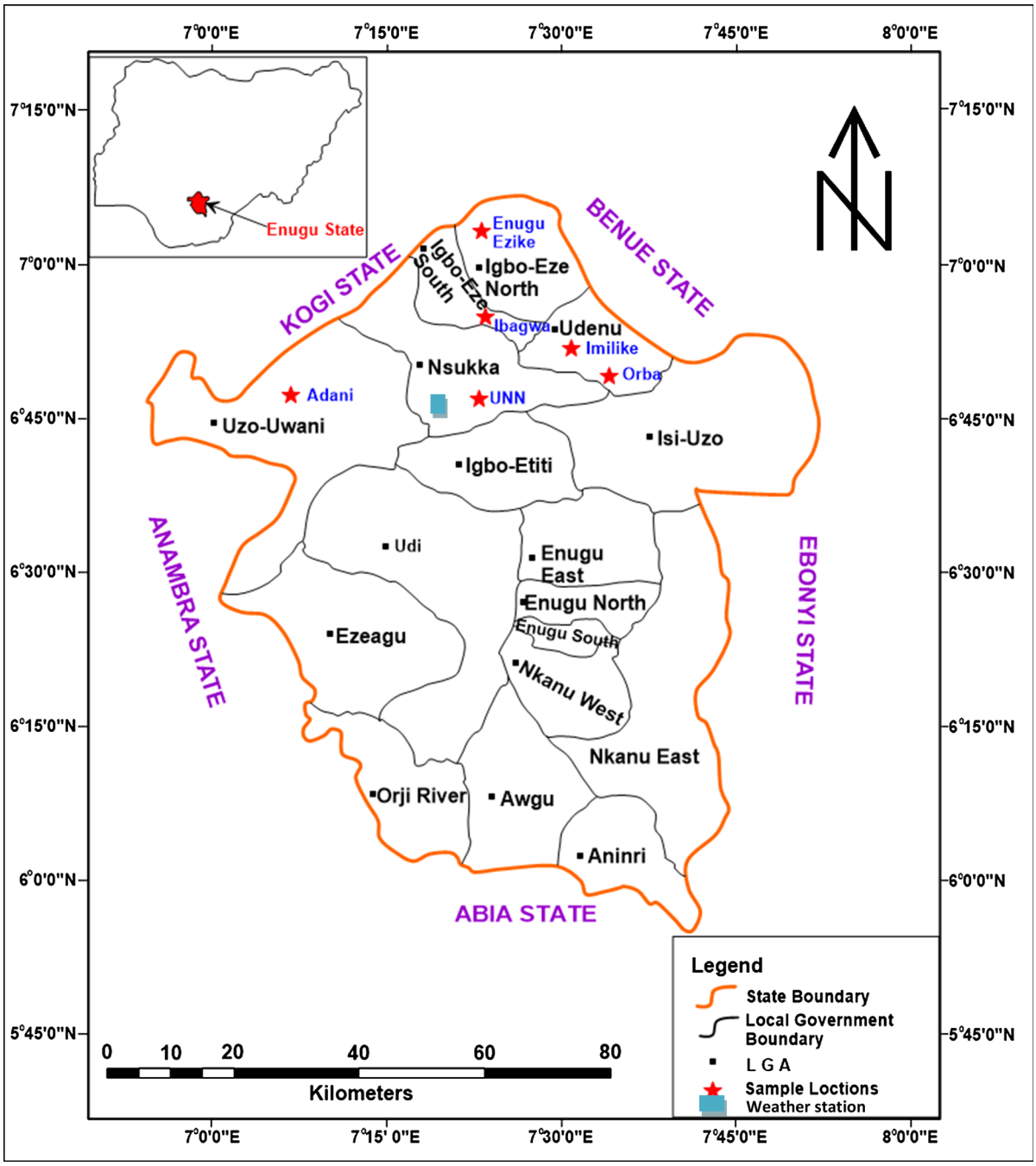


Fig. 1 Map of Enugu State showing the study locations

in the study areas. The volume (3606.8878 cm^3) was designed to accommodate the mean monthly rainfall. The trapping medium which served as preservative consisted of a mixture of 50 ml of glycerol, 25 ml of formalin and 5 ml of phenol (Njokuocha and Ukeje 2006), and samples were collected and replaced monthly. The collected samples were centrifuged at 2000*g* for 10 min and the residues collected.

The resulting residues were subjected to acetolysis treatment (Njokuocha et al. 2017) and finally stored in

Table 1 Sampling locations and the distance to meteorological station and level of urbanization

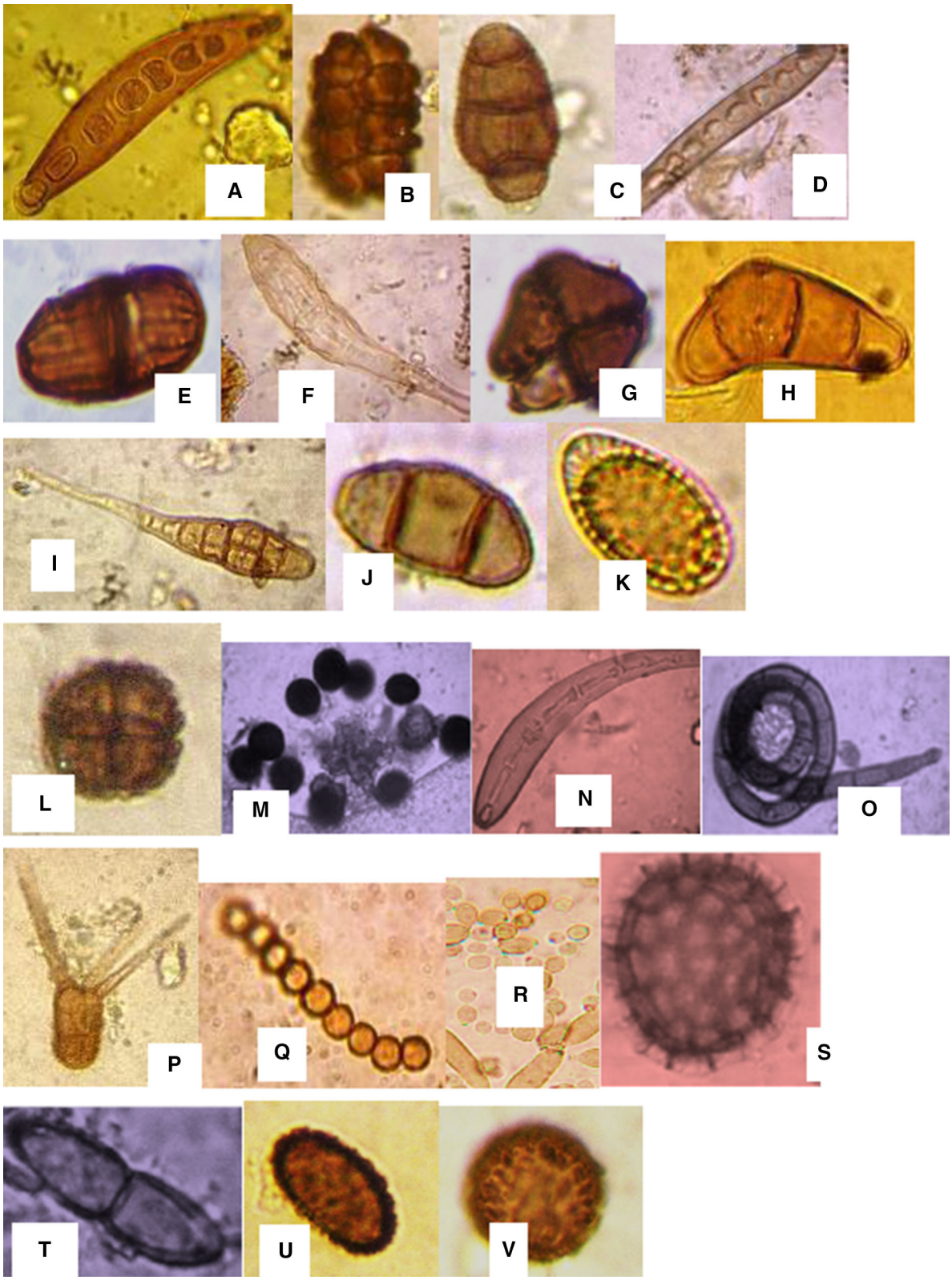
Location	Longitude (northing)	Latitude (easting)	Altitude (ft)	Distance of sampling point to weather station (km)	Urban level
UNN campus	068628.5	0074039.7	426	1.1	Urban
Orba	068600.5	0074393.5	465	7.6	Semi-urban
Adani	064405.6	0070105.2	700	54	Rural
Ibagwa	065535.7	0072422.1	1183	14	Rural
Imilike	068520.0	0075813.0	218	10	Rural
Enugu Ezike	065834.6	0072737.0	1290	19	Semi-urban
Botanical Garden, UNN	065158.7	0072443.0	1411	0.02	Urban

vials. Subsequently, routine spore counts and identification were carried out with WESO trinocular compound microscope at × 400 magnification and × 1000 for morphological examination and photomicrograph. Two drops of the agitated stock solution were placed on a microscope slide (25.4 mm × 76.2 mm) and covered with a cover slip (22 mm × 22 mm). This was prepared in three replicates, and the entire area of the mount (484 cm^2) was studied and the average value taken. Fungal spore identification was aided by photomicrographs and drawings of fungal spores in books and journals (Ogden et al. 1974; Burnett and Hunter 1998) and reference samples in the Department of Plant Science and Biotechnology, University of Nigeria, Nsukka. The abundance of fungal spores was determined by calculating the total amount of spores present in each trap, divided by the area of the modified Tauber Pollen Trap (cf. Hall 1994), and the value expressed as fungal spores/cm^2/month/year.

The meteorological data for the 12 months were provided by the Centre for Basic Space Science, National Space Research and Development Agency, Federal Ministry of Science and Technology, University of Nigeria, Nsukka. The station is located at a range of 0.02–54 km to the seven sampling sites. The meteorological parameters utilized in the assessment of the effects of weather conditions on the mean monthly airborne fungal spores were mean monthly relative humidity, rainfall, wind speed, air temperature, light intensity, atmospheric pressure and wind direction. The statistical correlation between the monthly spore concentration and mean monthly meteorological factors (n = 12) was calculated using Spearman's rho correlation coefficient method in IBM SPSS Statistics, version 20.0. The meteorological data used in the analysis were those of mean monthly temperature, rainfall, relative humidity, wind velocity, wind direction, light intensity and atmospheric pressure. The mean monthly spore counts were subjected to analysis of variance and mean separation test using Duncan multiple range test. OriginPro 8 software was used in plotting the graphs.

4 Results

A total of 49 fungal spore types were recorded in the atmospheric study (Fig. 2). Of this number, 18 most common and perennial airborne spore types were selected for Spearman's correlation with meteorological parameters. The most frequent and dominant spore types recorded were those of *Nigrospora, Endophragmiella, Ustilago, Botryodiplodia, Pithomyces, Venturia, Corynespora, Curvularia* and *Torula*. The highest number of fungal spores was recorded in the rainy season (May–October). Throughout the year, fungal spores were found to be present in large numbers with highest percentage abundance recorded in July, December, October, September, March and June (Fig. 3). However, the months with the highest frequency of maximum occurrence of fungal spore types were July (*Endophragmiella, Botryodiplodia, Nigrospora, Torula, Uromyces* and *Venturia*), December (*Corynespora, Curvularia, Gliomastix, Sporidesmium*, *Ustilago, Beltrania, Cercospora, Epicoccum, Pleospora* and grass smut), October (*Fusarium, Murogenella, Peziza, Spegazzinia, Stemphylum, Tetraploa and Tilletia)* and March (*Alternaria, Cladosporium, Drechslera/Helminthosporium, Pithomyces, Amerisporium, Asperisporium* and *Glomus*). The annual totals of monthly concentrations were highest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◀**Fig. 2** (1000 ×): Fungal spore genera identified in the study. **a**, **d** *Drechslera/Helminthosporium* type, **b**, **g** *Spegazzinia*, **c** *Pithomyces*, **e** *Botryodiplodia*, **f**, **n** *Corynespora*, **h** *Curvularia*, **i** *Alternaria*, **j** *Endophragmiella*, **k** *Ganoderma*, **l** *Dictyoarthrinium*, **m** *Nigrospora,* **o** *Helicosporium*, **p** *Tetraploa*, **q** *Torula*, **r** *Cladosporium*, **s** *Tilletia*, **t** *Venturia*, **u** *Gliomastix*, **v** *Ustilago*

for eight spore types, and this occurred mostly in July, December and March (Fig. 2). Statistically, there were significant differences in the mean airborne fungal spore abundance recorded monthly as well as those recorded at the locations (Table 2). The highest mean monthly spore abundance was recorded in July and this varied significantly ($p < 0.05$) from those of other months, and there were also significant differences ($p < 0.05$) between other monthly spore values (Table 2a).

At the study locations, the highest spore types were recorded in Enugu Ezike, followed by Adani, Botany Garden UNN and UNN campus, while the least were recorded in Ibagwa and Imilike (Fig. 4). Similarly, the highest mean spore abundance was recorded at Adani and this varied significantly ($S < 0.05$) from those of other locations, and there were also significant differences between other spore values (Table 2b). Of the fungal spore types, spores of *Nigrospora* were the most frequent and abundantly recorded spore genera at the locations with highest values occurring at five locations (UNN campus, Orba, Adani, Imilike and Enugu Ezike) and accounting for 24.0% of the annual total spore counts. This was followed by *Endophramiella*, *Ustilago*, *Botryodiplodia*, *Pithomyces* and *Venturia* among others. Majority of the spore types identified never exceeded 1% of the annual spore counts, and they include Aspergillus, *Brachysporium, Coprinus, Cordana, Cucurbitaria, Dictyoarthrinium, Didymella, Diplocladiella, Diplococcum, Exosporium, Fusarium, Glomerularia, Glomus, Helicosporium, Mycoleoptodiscus, Plasmopara, Puccinia, Russula, Sirodesmium* and *Sirosporium*. High fungal spore diversity and abundance were recorded more in areas located at higher altitudes such as Enugu Ezike, Ibagwa, Botanical Garden and Adani (Table 1).

On a seasonal basis, the highest spore abundance was recorded in the rainy season with 56.8% of the total spore count recorded particularly in July across the seven locations and subsequently declined towards the dry season. The major contributing spore genera during the rainy season were *Nigrospora, Endophragmiella, Botryodiplodia, Tetraploa, Torula, Venturia, Fusarium* and *Ganoderma,* while *Ustilago, Corynespora, Curvularia, Sporidesmium, Cladosporium,* grass smut, *Glomus* and *Asperisporium* were dominant during the dry season (Fig. 3).

Spearman's correlation analysis performed between performed between the mean monthly spore abundance of 18 perennial spore genera, and some meteorological factors showed that there were significant correlations between some of the correlated variables. There were significant correlations ($n = 12$, $p < 0.05$) between mean temperature and spore abundance of four spore genera. Positive correlation was noted for only *Cladosporium* and negative for *Endophragmiella, Torula* and *Venturia*, while others were not significantly correlated with temperature. A significant ($n = 12$, $p < 0.01$) positive correlation was recorded between relative humidity, rainfall, wind direction and spore abundance of *Torula* ($n = 12$, $p < 0.05$). There were also significant positive correlation ($n = 12$, $p < 0.05$) between light intensity and spore abundance of *Alternaria* and *Cladosporium* and significant negative correlation with *Uromyces*. The results also showed that atmospheric pressure was significantly positively correlated ($n = 12$, $p < 0.05$) with the spore abundance of *Endophragmiella, Venturia* and *Torula* (Table 3). There was no significant correlation between abundance of spore types of *Corynespora, Curvularia, Drechslera/Helminthosporium, Botryodiplodia, Ganoderma, Gliomastix, Nigrospora*, *Pithomyces, Spegazzinia, Tetraploa* and *Ustilago* and all the meteorological variables.

5 Discussion

Researchers have demonstrated that airborne fungal spore distribution and abundance vary across the unique atmospheric areas of the world. The fungal spores considered to occur in high concentration in the temperate regions are not always as ubiquitous in some regions of the tropics (Damialis and Gioulekas 2006; Ianovici et al. 2013; Almaguer et al. 2015). This may have been the situation in this study regarding the low abundance of a few spore kinds including *Cladosporium* and *Alternaria* which are extensively mentioned in the temperate environment as dominant airspora and more generally trapped spore types in the

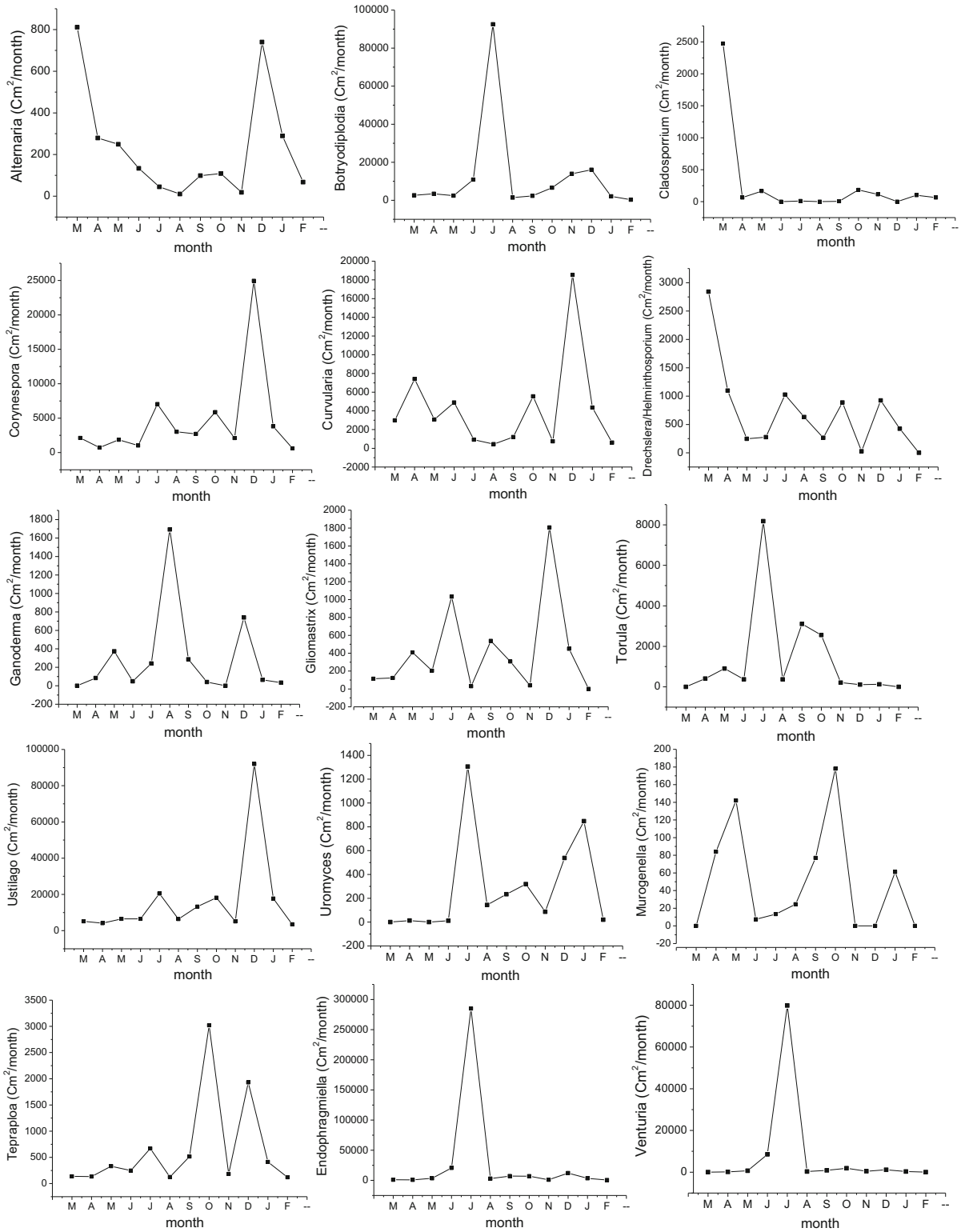


Fig. 3 Cumulative abundance of monthly airborne spores of the most dominant fungal genera recorded in the areas of study

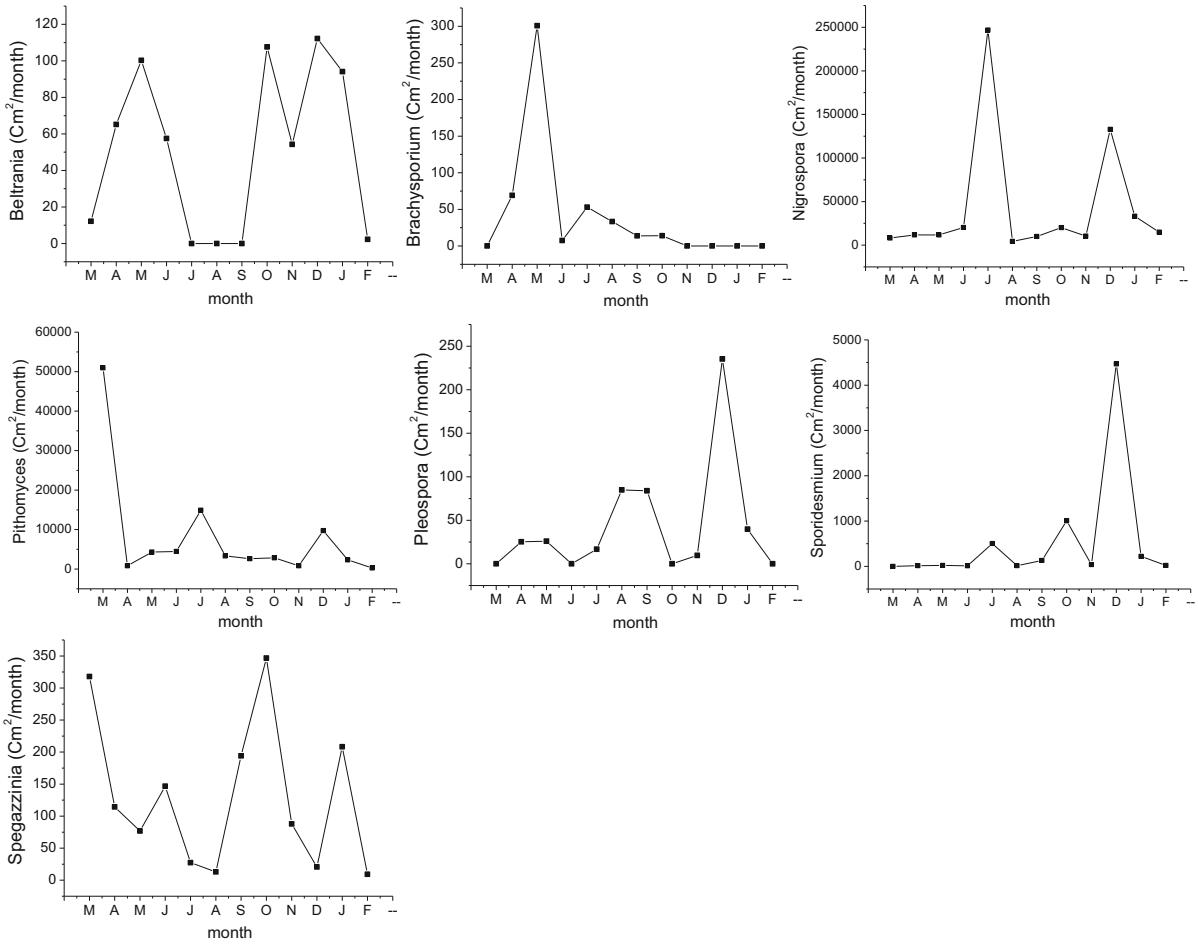


Fig. 3 continued

environment (Sakiyan and Inceoglu 2003; Rodriguez-Rajo et al. 2005; Damialis and Gioulekas 2006; Jedryczka 2014). The low abundance of *Cladosporium* spore types when compared to reports from temperate environments may be attributed to the fact that the sampler used in this study is non-volumetric and favours collection of larger spore types over smaller spores due to its reliance on gravity settlement, a factor which is affected greatly by air turbulence in contrast to volumetric samplers used in most aerobiological studies in temperate countries which are designed for quantitative determination of airspora.

In the study, the investigated areas showed the presence of large quantity of fungal floral diversity and high abundance of spore counts which may be attributed to the semi-urban and rural nature of the study areas (Kasprzyk and Worek 2006; Oliveira et al. 2009). The notable variations in abundance of airborne fungal spores recorded at the locations may be attributed to varying climatic conditions and different other unique environmental factors. In fact, differences in phytoecology, microclimate and altitudinal conditions may account for the very high spore values observed in the spore counts at Adani. Adani is a rural area associated with forests, woodlands, large acres of rice farms, grasses and other agricultural crops which are hosts to numerous diverse fungi species that release immense quantity of fungal spores during wet seasons and harvest periods. According to Friesen et al. (2001) and Corden et al. (2003), an increase in spore cloud in the atmosphere has been associated with grasses and period of wheat harvest. Equally differences in spore abundance and diversity across different locations can be attributed to differences in

microclimate and floristic composition of the vegetation of the region of each location (Awad 2005; Ianovici et al. 2013). Some fungi may be host specific (Yang et al. 2012) barring other environmental variables; therefore, it is more likely that the more heterogeneous the vegetation, the more diverse the fungal community. This may also explain the differences in abundance and diversity of spore genera across the locations. In addition, variations in the distribution of fungal spore abundance at the locations may be attributed to the proximity and abundance of the source fungal spores to the samplers and the botanical character of the region. Airborne fungal spore concentration has been mentioned to depend on crop diversity and proximity to grassland regions (Corden et al. 2003; Pepeljnjak and Segvic 2003). The common fungal genera contributing to the abundance of spores in the study areas included *Nigrospora, Endophragmiella, Botryodiplodia, Ustilago, Pithomyces, Corynespora, Venturia* and *Curvularia*. This is comparable to the findings of Njokuocha et al. (2017) in Enugu south and Essien et al. (2013) in the middle belt of Nigeria.

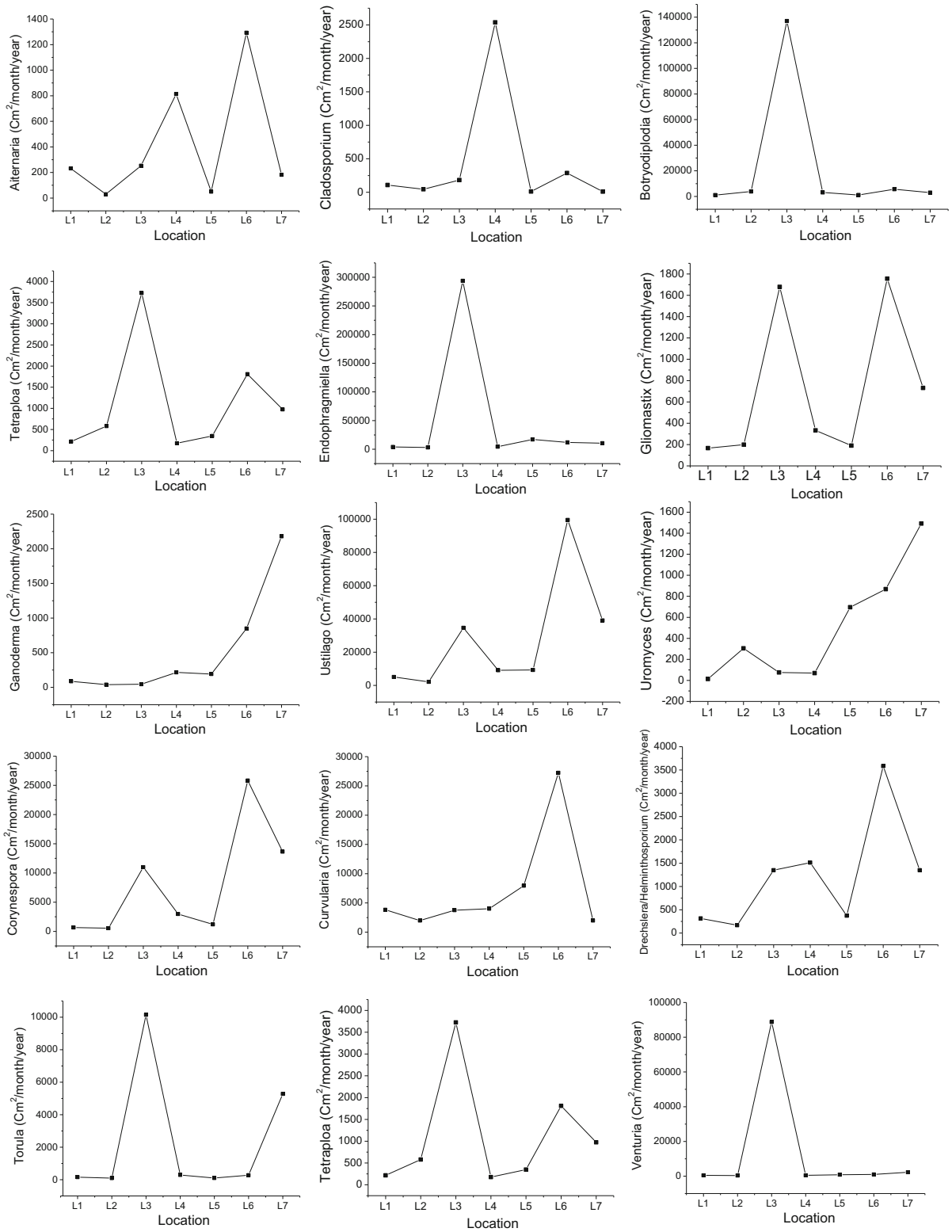
Fig. 4 Annual abundance (spores/cm^2/year) of the most dominant fungal genera recorded in the areas of study. L1 (UNN Campus), L2 (Orba), L3 (Adani), L4 (Ibagwa), L5 (Imilike), L6 (Enugu Ezike) and L7 (Botanic Garden, UNN)

Variations in the periodic abundance of airborne fungal spore record have been reported by several authors (Okten et al. 2005; Ataygul et al. 2007; Grinn-Gofron 2008; Essien et al. 2013; Jedryczka 2014; Sadys et al. 2006). Their findings agree to a large extent with the results of this present study in which significant differences were observed in the monthly spore abundance. The highest amount of airborne fungal spores was recorded in July, a period when the environment is wet, temperature relatively low and windy in the region. The value of fungal spores recorded in July was found to be significantly different from those recorded in other months. During this wet period, weather factors such as rainfall and relative

Table 2 a, b Mean values of airborne fungal spore abundance (cm^2/month) recorded at the locations and monthly

Location	Mean spore abundance (cm^2/month)
a	
Adani	124,017^a
Enugu Ezike	33,163^b
Botanical Garden, UNN	27,777^c
Ibagwa	13,520^d
Imilike	8688^e
UNN Campus	3426^f
Orba	2870^h
Month	
b	
March	20,276^f
April	6088^j
May	60,831^b
June	12,739^g
July	129,576^a
August	4594^k
September	23,520^e
October	25,520^d
November	8099^i
December	58,579^c
January	12,126^h
February	3995^i

Mean values with the same letter superscripts are not significantly different ($p < 0.05$)


Alternaria (Cm2/month/year)
Cladosporium (Cm2/month/year)
Botryodiplodia (Cm2/month/year)
Tetraploa (Cm2/month/year)
Endophragmiella (Cm2/month/year)
Gliomastix (Cm2/month/year)
Ganoderma (Cm2/month/year)
Ustilago (Cm2/month/year)
Uromyces (Cm2/month/year)
Corynespora (Cm2/month/year)
Curvularia (Cm2/month/year)
Drechslera/Helminthosporium (Cm2/month/year)
Torula (Cm2/month/year)
Tetraploa (Cm2/month/year)
Venturia (Cm2/month/year)
L1 L2 L3 L4 L5 L6 L7
Location

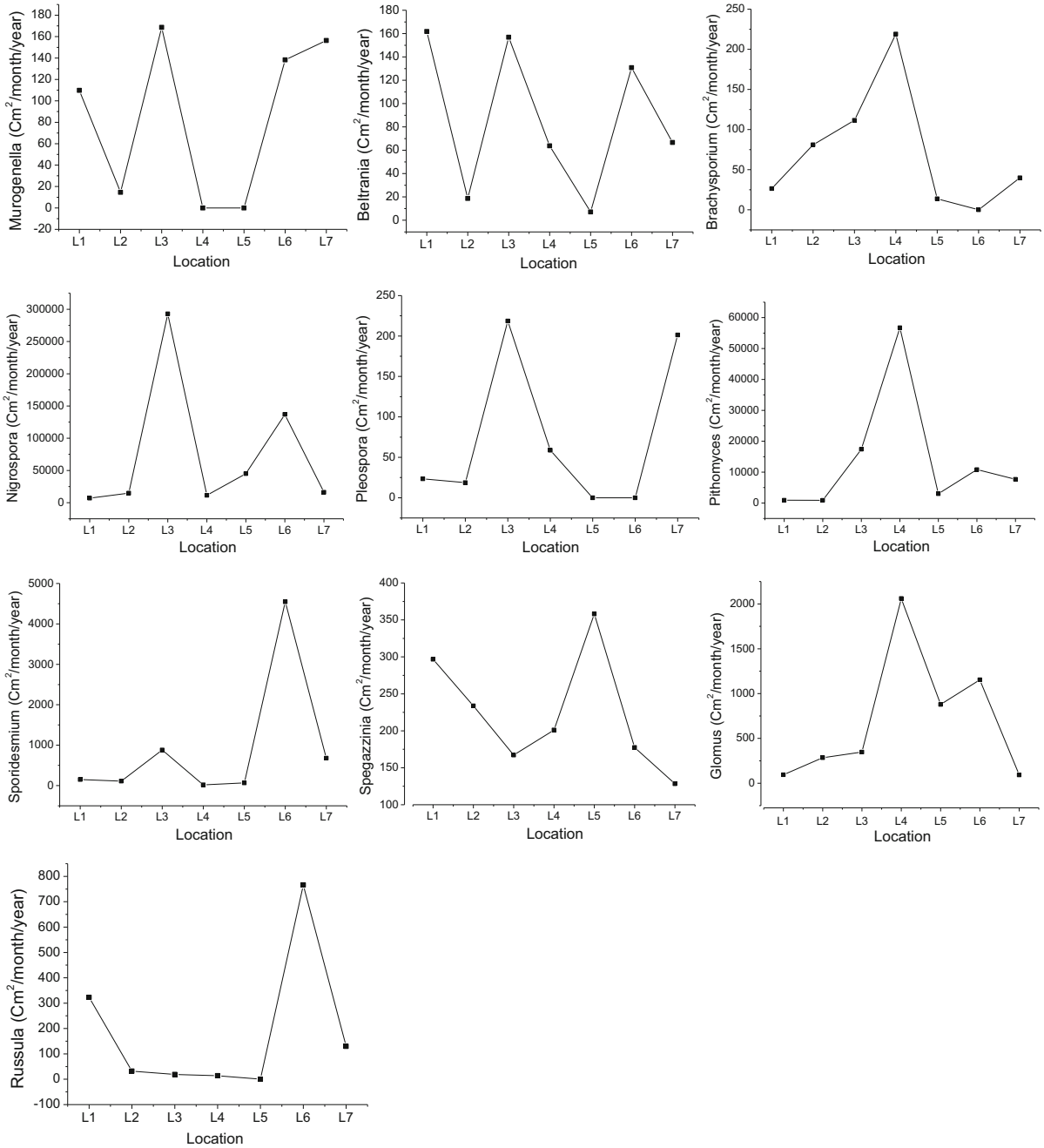


Fig. 4 continued

humidity have been reported to favour the growth, sporulation and spore dispersal (Ebner et al. 1989; Herrero et al. 1996; Rodriguez-Rajo et al. 2005) of most fungi leading to an increase in spore abundance in the atmosphere.

Variation in altitudinal level appears to have played important role in influencing the quantity and diversity of airborne fungal spore genera recorded at the various locations. In Enugu Ezike, Ibagwa, Botanical Garden and Adani where the altitudinal locations are high, there were comparatively more airborne fungal spore

Table 3 Contribution of fungal spores and the results of Spearman's rank correlation between monthly abundance (cm^2/year) of spores and some weather factors in Enugu North, Nigeria

Taxon	Annual contribution		Temperature	Relative humidity	Rainfall	Light intensity	Wind direction	Atmospheric pressure	Wind speed
	Count (cm^2/year)	%							
Alternaria	2851.75	0.132	0.469	− 0.427	− 0.315	0.594*	− 0.490	− 0.277	0.343
Cladosporium	3180.25	0.146	0.606*	− 0.359	− 0.218	0.683*	− 0.127	− 0.307	0.092
Corynespora	55,808.99	2.559	− 0.392	0.161	0.021	− 0.133	0.056	0.221	− 0.154
Curvularia	50,722.27	2.325	0.217	− 0.203	− 0.014	0.427	− 0.392	0.025	0.392
Drechslera/Helminthosporium	8651.85	0.397	0.168	0.070	0.021	0.420	− 0.102	0.053	− 0.238
Endophragmiella	344,871.4	15.811	− 0.601*	0.469	0.259	− 0.280	0.273	0.644*	− 0.266
Botryodiplodia	154,604.2	7.088	− 0.098	0.168	0.000	0.273	− 0.007	0.396	− 0.084
Ganoderma	3606.79	0.165	− 0.573	0.490	0.357	− 0.371	0.077	0.389	− 0.147
Gliomastix	5054.47	0.232	− 0.301	0.119	− 0.028	− 0.056	− 0.084	0.375	0.098
Nigrospora	524,179.8	24.032	− 0.317	− 0.161	− 0.245	0.000	− 0.336	0.123	0.399
Pithomyces	97,441.82	4.467	− 0.175	0.308	0.063	0.042	0.231	0.312	− 0.566
Spegazzinia	1562.78	0.072	− 0.217	0.042	0.231	0.161	0.210	0.175	− 0.112
Sporidesmium	6449.68	0.296	− 0.350	− 0.049	− 0.119	− 0.315	− 0.021	0.140	0.180
Tetraploa	7829.88	0.359	− 0.322	0.154	0.119	− 0.056	0.140	0.420	− 0.021
Torula	16,346.39	0.749	− 0.627*	0.767**	0.673*	− 0.347	0.592*	0.902*	− 0.333
Uromyces	3520.47	0.161	− 0.50	0.081	− 0.028	− 0.676*	0.049	0.149	0.035
Ustilago	198,865.9	9.117	− 0.462	0.203	0.084	− 0.189	0.049	0.364	− 0.077
Venturia	94,181.45	4.318	− 0.650*	0.545	0.434	− 0.322	0.406	0.750**	− 0.238

*Significant = $p < 0.05$; **highly significant = $p < 0.01$

abundance and diversity for most of the spore genera recorded in the study. These results are comparable to the findings of Khattab and Levetin (2008), Li et al. (2010) and Damialis et al. (2017) who noted that sampling heights like other variables influence the abundance of different bioparticles recorded in the air. They, however, observed that larger spores were prevalent at the lower level, while the smaller spores were more abundantly recorded at higher elevation. Higher altitude has better unobstructed wind movement and therefore receives more spores and other biological fragments from both local and long distance transports.

Meteorological conditions have notable influence on the fungal spore production, dispersal and deposition as has been reported in numerous research works (Burch and Levetin 2002; Oliveira et al. 2009; Grinn-Gofron and Bosiacka 2015) all over the world. The results of the present work on the relationship of airborne fungal spore level and prevailing meteorological factors compared favourably to those obtained by previous researchers. Correlation coefficient analysis showed that *Alternaria* was positively and significantly correlated with light intensity. Comparable finding has been established by Fernandez et al. (1998) in which sunshine hours was positively correlated with *Alternaria*. Species of *Alternaria* are dematiaceous anamorphic fungi belonging to Ascomycota. They have been reported to cause significant agricultural losses and are important human aeroallergens (Robert et al. 2003; Pastor and Guarro 2008; Nowicki et al. 2012). Airborne *Cladosporium* spore types which have been reported as the dominant airborne fungal spore type in most studies in the temperate environment were, however, recorded in low abundance in this work. This finding is comparable to that of Njokuocha et al. (2017) and Agwu et al. (2004).

Despite the low values, the spore occurrence of *Cladosporium* recorded in this study was found to have positive significant correlation with temperature and light intensity and non-significant negative correlation with rainfall and relative humidity. Comparatively, significant positive correlation with temperature and negative correlation with relative humidity and rainfall have been reported (Katial et al. 1997; Molina et al. 1998). Also positive correlation with temperature was reported by Grinn-Gofron (2008), Rodriguez-Rajo et al. (2005) and Grinn-Gofron et al. (2017). Damialis and Gioulekas (2006) in their dynamic regression models were able to relate the abundance of *Cladosporium* recorded in their work to influence of solar radiation.

The spore abundance of *Endophragmiella*, an anamorphic fungus, was found to be significantly negatively correlated with temperature and significantly positively correlated with atmospheric pressure. Comparable results have been reported by Njokuocha et al. (2017). The negative relationship shown with temperature and the positive relationship with atmospheric pressure, rainfall and relative humidity are in conformity with its nature as a wet-air spore. This also coincided with its highest occurrence during the rainy season. The spore type of *Torula* seldom reported in aerobiological studies contributed meaningfully to the general spore count. It had negative significant correlation with temperature and significant positive relationship with relative humidity, rainfall, wind direction and atmospheric pressure. These results are in contrast to the findings of Grinn-Gofron (2008) who reported negative significant correlated with relative humidity and rainfall and positive correlation with temperature. The spores of *Torula* like some other Ascomycetes may be predisposed to higher dispersal during periods of higher temperature and low humidity. *Torula* is a mitosporic, ubiquitous and cosmopolitan fungus and is recorded in airspora in the tropics. Another fungus whose basidiospores have been scarcely reported in aeromycological studies is *Uromyces,* the spores of which contributed meaningfully to the general spore abundance in this study. The spore values increased during the late rainy to early dry season when the environment was relatively wet with considerable period of sunshine. The negative significant correlation with light intensity and the non-significant positive correlation with relative humidity suggest that the spore release is influenced by humidity levels. *Uromyces* species belongs to the rust fungus of the Basidiomycota and are important plant pathogens (Barilli et al. 2012; Acevedo et al. 2013).

Another fungal species worthy of mention is *Venturia.* The spore value was significantly negatively correlated with temperature and none significantly positively correlated with rainfall and relative humidity. The notable increase in abundance of its ascospores during the wet period of the year is in agreement with its classification as a wet-air spore. Hernandez-Trejo

et al. (2012) reported that rainfall affects the release of its ascospores in the environment. Secondly, the significant positive correlation of the spores with atmospheric pressure is comparable to Jedryczka (2014), who explained that the natural mechanism in fruit bodies is that they react to pressure of atmospheric water which directly causes osmotic changes leading to ascospore discharge into the atmosphere. Also, Ascomycetes are fundamentally known to be hydrostatic in character in which the asci are caused to be turgid due to high osmotic pressure resulting from direct water absorption from the ambient air or by swelling of mucilage within the asci (Ingold 1971; Moore-Landecker 1990). Such reactions result in the ejection and release of ascospores more frequently during and after rainfall when the relative humidity is high (Allitt 1986; Grinn-Gofron and Bosiacka 2015).

Of importance in the environment are other recorded fungal spore genera some of which are potential pathogens, secondary or opportunistic invaders of plants and humans, and possibly allergenic in nature. *Drechslera* which was recorded in considerable quantity is pathogenic and potentially allergenic (Rolston et al. 1985; Chakraborty et al. 2001; Sunder et al. 2005; Jadon and Shah 2012). *Corynespora* whose conidia were also recorded in high abundance during the wet season causes leaf spot disease of plants and human subcutaneous infection (Oluma and Amuta 1999; Pernezny et al. 2003; Huang et al. 2010; Sandeep et al. 2016; Chairin et al. 2017). *Curvularia* is a facultative pathogen of many plants in tropical and subtropical countries, contaminant of seed crops, household materials and opportunistic fungus on immunocompromised patients (Carter and Boudreaux 2004; Kamaluddeen and Abhilasha 2013; Akram et al. 2014).

Botryodiplodia which is a major pathogen of food crops was recorded abundantly during the wet season, a period during which it causes severe leaf rot of *Colocasia esculenta,* a staple crop in south-eastern Nigeria. Among other fungi recorded in high abundance include *Nigrospora* found in decaying plant matter and soil. It is potentially allergenic and causes leaf spot diseases across a wide range of plant species (Wright et al. 2008; Soylu et al. 2011). *Ustilago,* a parasitic and dimorphic smut fungus, causes variety of plant diseases and has been associated with peritonitis of humans (Kahmann et al. 2000; McNeil and Palazzi 2012). *Pithomyces* which consists of numerous dematiaceous saprobic fungal species grows on dead plants, and some species cause infections of humans and animals (Ozomen et al. 2008; da Cunha et al. 2014). Recorded were the spores of *Ganoderma*, a bracket and wood-decaying fungus that grows on hardwood tree species. Other fungi genera whose spores were recorded in considerable amount are *Spegazzinia, Sporidesmium, Tetraploa* and *Gliomastix*. Some of them have been mentioned to be saprophytes, pathogenic to plants, allergenic to humans and causes variety of human infections.

6 Conclusion

The aero-mycofloral study revealed the presence of diverse and abundant fungal spore genera in the study areas, varying notably across the locations, months and seasons in their relative abundance. Meteorological factors influenced significantly the abundance of some of the fungal spore genera correlated. A continuous survey of airborne fungal spores for a longer period is recommended for the region.

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