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## Effects of weather conditions on selected airborne fungal spores in the southern part of the state of Enugu, Nigeria

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### Abstract

A study of airborne fungal spore was carried out at nine locations in the southern part of the state of Enugu, Nigeria, from March 2005 to February 2006. The aim of the study was to ascertain the variations in selected fungal spore types at the sites owing to weather conditions. The variation in airborne fungal spores of 14 taxa was studied using modified Tauber pollen traps including *Alternaria*, *Corynespora*, *Curvularia*, *Drechslera* type, *Endophragmiella*, *Botryodiplodia*, *Ganoderma*, *Gliomastrix*, *Nigrospora*, *Pithomyces*, *Spegazzinia*, *Sporidesmium*, *Tetraploa* and *Ustilago*. The frequency of the spore types recorded showed considerable variation. The highest spore counts were recorded in July, June and October. The highest numbers of fungal spores were recorded during the rainy season (June–October) to early dry season (November–December). The peak of occurrence of most selected fungal spore types was July. The highest percentages of fungal spores were documented at the recording stations Mgbowo Junction, UNTH Ituku Ozalla and Oji River Express Junction. Spearman's correlation analyses were performed for the monthly amounts of the fungal spore types and monthly meteorological factors. The numbers of *Curvularia*, *Nigrospora* and *Sporidesmium* was significantly correlated with relative humidity, while those of *Endophragmiella*, *Pithomyces* and *Nigrospora* were significantly correlated with temperature. A significant correlation was also found between the number of *Nigrospora* spores and light intensity and *Sporidesmium* spores and wind velocity. Relative humidity and temperature seem to be the most important weather conditions affecting the frequency of the selected spore types in the atmosphere.

**Keywords:** *Nigrospora*, *Pithomyces*, *Endophragmiella*, *temperature*, *relative humidity*, *correlation*

Fungal spores are among the most numerous and widely distributed aerobiological particles in the atmosphere throughout the world (Ataygul et al. 2007), and frequently occur from the rainy season through to the early/late dry season in tropical West Africa, although their occurrence fluctuates in time and space (Melia 1984; Agwu et al. 2004; Njokuocha & Agwu 2007). Their abundance is enhanced by their ability to respond to growth and sporulation at varying weather conditions for the different species of mould (Grinn-Gofron 2008; Ianovici et al. 2013). The relative abundance and diversity of the spores in the atmosphere are influenced considerably by the interaction of many variables such as meteorological factors, host vegetation complexity, decaying materials of plants and season of sporulation.

The release of fungal spores in the air has been reported to show periodic rhythms, the basis on which they have been distinguished into dry-air spora and wet-air spora (Troutt & Levetin 2001). Some members of the Ascomycotina are often associated with low humidity, high temperature and wind speed, while some other members of the Ascomycetes and Basidiomycetes are dominant in humid and wet conditions (Hjelmroos 1993; Levetin 1995; Katial et al. 1997). Although some fungal spores are more abundant during wet conditions, spore depressions have been recorded during period of rainfall due to excessive rainfall that washes spores out of the atmosphere (Burge 1986).

Many authors have correlated weather conditions with the abundance and prevalence of certain spore

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types in the atmospheres of climatically different locations (Cadman 1991; Hasnain 1993). Differences in microclimate and floristic composition of the areas are suggested as important determinant factors. Equally, variations in the diversity and abundance of fungal spores have been observed during different weather conditions in both temperate and tropical climates (Adhikari et al. 2004; Njokuocha & Agwu 2007).

Increase in atmospheric temperature and low relative humidity have been correlated with increase in certain spore taxa of the dry-air spora, such as *Alternaria* and *Cladosporium*. In contrast, high relative humidity, short rain fall and low temperature have been positively correlated with increase in certain wet-air spora such as *Ustilago* and *Venturia* (Sabariego et al. 2000; Troutt & Levetin 2001).

Many fungi species are saprophytes invading virtually all stages of plant growth and they are also plant pathogens causing severe economic losses. Therefore, a good knowledge of the composition of airborne fungal spores of an area is important in agriculture because it will help in the forecast and control of certain disease conditions that may lead to epidemic and crop failure. High concentration of fungal spores in the air may not only elicit allergic reactions to immunocompromised individuals and asthmatic patients but also may serve as indicator of the level of atmospheric pollution (Grinn-Gofron & Strzelczak 2011).

In Nigeria, there are limited studies on the types, abundance and effect of meteorological conditions on airborne fungal spores. Studies by Agwu and Osibe (1992) and Agwu (2001) showed that airborne fungal spores were among the dominant airborne palynomorphs circulating in the atmosphere and constituted about 32.6% and 34.2% of the total palynomorphs recorded, respectively. In a similar study by Agwu et al. (2004), fungal airborne fungal spores constituted 77.7% of the total fungal spores recorded over a six-month period at a height of about 1.65 m. The spores of *Cladosporium*, *Ustilago*, *Nigrospora*, *Drechslera-Helminthosporium* type, *Pithomyces*, *Curvularia* and *Alternaria* were among the commonly recorded spore types in most of the aerobiological studies in Nigeria (Agwu 2001; Agwu et al. 2004; Njokuocha & Osayi 2005; Njokuocha & Agwu 2007; Essien et al. 2013). Variation in airborne fungal spore abundance at different heights have been reported (Njokuocha & Agwu 2007) and the high spore abundance at the lower level was attributed to the release of spore cloud by the abundant grasses, weeds and shrubs, which are hosts to these fungi in the surrounding vegetation. Studies conducted in Anyigba, a derived savanna environment of the middle belt of Nigeria, showed that the

fungal spore record constituted also about 33.4% of the total palynomorphs identified (Essien et al. 2013) with *Curvularia*, *Pithomyces*, *Nigrospora* and *Botryodiplodia* being the dominant spore types recorded (Essien et al. 2013). This study conducted in southern part of the state of Enugu is part of an ongoing research effort to determine the abundance and potential effects of some meteorological factors on airborne fungal spores in Nigeria.

## Material and methods

### Study area

The investigation of airborne fungal spores was conducted over a period of 12 months (March 2005 to February 2006) at nine localities in the southern part of Enugu (Iwollo I and II, Oji River Express Junction, Oji River Park, Ngwo Express Junction, Mgbowo Junction, Awgu Village, Agbani General Hospital, and University of Nigeria Teaching Hospital [UNTH] Ituku Ozalla; Figure 1, Table I). The nine study areas are situated within fast growing suburban towns in five local government areas of Enugu. The state belongs to the humid tropical region with mean annual rainfall varying from 786 mm to 2098 mm. The average monthly air temperature oscillates between 24 °C and 29 °C. The wind system is influenced mainly by the North-east Trade during the dry season that introduces the cool, dry Harmattan condition from the Sahara around early November to late January and the southwest (SW) Monsoon, which is responsible for the rainfall (rainy season) from May to October. The climate is, therefore, influenced by two distinct seasons, the rain season (May–October) and the dry season (November–April). Generally, the vegetation of Enugu belongs to the mosaic lowland rainforest and secondary grassland and increase in human activities, especially agricultural practices, has led to the fragmentation of the vegetation (Agwu 1997).

The vegetation around sites Iwollo I and II is fragmented into cultivated farmlands, oil palm bushlands with abundant grasses, patches of mature nature forests and plantations of *Anacardium occidentale* L. In Oji River Express Junction, the vegetation is predominantly open woodland shrub grassland with *Daniellia oliveri* (Rolfe) Hutch. et Dalziel, *Terminalia superba* Engl. et Diels, *Hymenocardia acida* Tul., *Dialium guineense* Willd., *Vitex doniana* Sweet and *Prosopis africana* Taub., amongst others dominating the tree species. Bordering the Oji River Park are cassava farms with abundant weeds and isolated stands of former woodland vegetation such as *Parkia biglobosa* (Jacq.) R.Br. ex G.Don, *Bridelia ferruginea* Benth. and *Daniellia oliveri*.

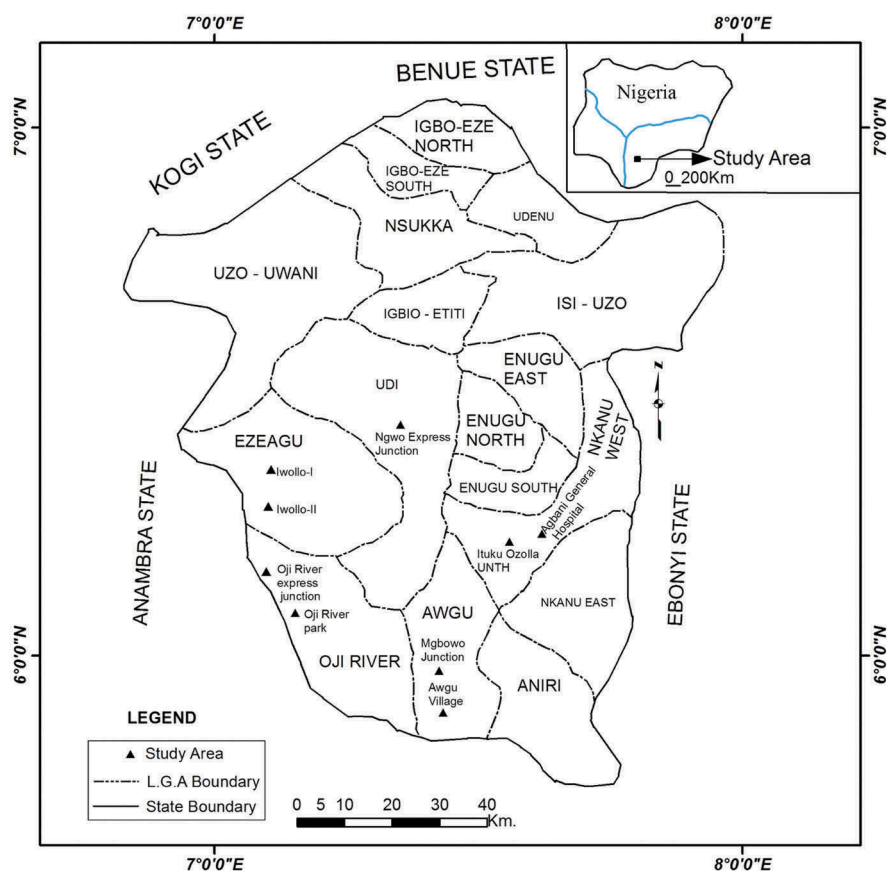


Figure 1. Map of the state of Enugu, Nigeria, showing the study locations.

Around Ngwo Express Junction, the natural woodland vegetation has been converted in most parts into farmlands. Growing around the area are indigenous and exotic trees species such as *Daniellia oliveri*, *Parkia biglobosa*, *Anthocleista vogelii* Planch., *Pinus caribaea* Morelet, *Gmelina arborea* Roxb. and *Gliricidia sepium* (Jacq.) Kunth. The vegetation around Mgbowo Junction consists of farmlands, relic forests, oil palm forests and remnants of the original woodland flora scattered in patches in the area. The vegetation in Awgu Village is similar to that at Mgbowo Junction only that some areas of the woodland vegetation and relic forests in Awgu are less disturbed by human activities.

Surrounding the Agbani General Hospital site is farmland, relics of woodland and lowland rainforest species. The vegetation around the UNTH Ituku Ozalla is composed of open woodland grassland and farmlands which becomes more compact during the wet season.

#### Atmospheric samplers

The samplers were located in the sampling areas and the selection of sampling sites was influenced by the semi-urban distribution of the area. The sampling

instruments were modified Tauber pollen trap ( $3606.89 \text{ cm}^3$ ) mounted at a height of about 5 cm at strategic locations in the study area. The volume was designed to accommodate the mean monthly rainfall of the area. The trapping medium consisted of a mixture of 50 ml of glycerol, 25 ml of formalin and 5 ml of phenol (Njokuocha & Ukeje 2006); samples were collected monthly. The collected samples were subjected to centrifugation at 2000 rounds per minute (rpm) for 10 minutes and the residues collected that were subsequently treated with aceto-lysis. The final residues were stored in vials for microscopic analysis. Two millilitres of the agitated stock sample were dropped on a microscope slide and covered with a cover slip.

Subsequently, routine spore counts and identification were carried out with a WESO trionocular compound microscope ( $400\times$ ) on the entire surface area of  $484 \text{ mm}^2$  of the cover slip. Fungal spore identification was based on photomicrographs and illustrations of fungal spores in Ogden et al. (1974) and Burnett and Hunter (1998), and on reference samples in the collection of the Department of Plant Science and Biotechnology, University of Nigeria, Nsukka. The abundance of fungal spores was determined by calculating the

Table I. Detailed information of the study locations in the southern part of Enugu, Nigeria and results of spore collection 2005–2006.

|   | Location                         | Longitude          | Latitude             | Altitude (Ft) | Distance of sampling site to meteorological station (km) | Total fungal spores (cm <sup>2</sup> /year) | Percentage spores total (%) |
|---|----------------------------------|--------------------|----------------------|---------------|----------------------------------------------------------|---------------------------------------------|-----------------------------|
| 1 | UNTH<br>Ituku<br>Ozalla          | 06° 17'<br>41.6" E | 007° 28'<br>28.6"N   | 711           | 9.3                                                      | 56 211                                      | 16.0                        |
| 2 | Iwollo 11                        | 06° 26'<br>21.4" E | 007° 16'<br>54.1"N   | 882           | 50.2                                                     | 3622                                        | 1.0                         |
| 3 | Ngwo Express<br>Junction         | 06° 25'<br>25.1" E | 007° 24'<br>23.3"N   | 1269          | 20.4                                                     | 10 230                                      | 2.9                         |
| 4 | Oji River<br>Express<br>Junction | 06° 16'<br>31.5" E | 007° 16'<br>58.2"N   | 902           | 33.6                                                     | 49 280                                      | 14.1                        |
| 5 | Awgu Express<br>Junction         | 06° 05'<br>39.2" E | 007° 29'<br>38.8"N   | 562           | 29.2                                                     | 132 772                                     | 37.9                        |
| 6 | Iwollo 1                         | 06° 26'<br>22.8" E | 007° 16'<br>59.0"N   | 882           | 49.0                                                     | 64 919                                      | 18.5                        |
| 7 | Oji River Park                   | 06° 25'<br>73.0" E | 007° 27'<br>00.1"N   | 75            | 42.0                                                     | 4148                                        | 1.2                         |
| 8 | Agbani General<br>Hospital       | 06° 18'<br>36.4" E | 007° 33'<br>5915.9"N | 735           | 13.5                                                     | 20 653                                      | 5.9                         |
| 9 | Awgu village                     | 06° 03'<br>06.8" E | 007° 28'<br>21.10"N  | 400           | 54.6                                                     | 8538                                        | 2.44                        |

total amount of spores present in each trap, divided by the area of the modified Tauber Pollen Trap (cf. Hall 1994). The values were expressed as fungal spores/cm<sup>2</sup>/month/year.

Fourteen fungal spore types were selected for analysis, because they were widely spread across the study locations and constituted 75.4% of the total quantity of spores recorded in the entire study. They were selected for the purposes of correlation with some meteorological factors as bases of understanding the relationship between spore abundance and meteorological factors, and that does not suggest that they are the most dominant airspora in Nigeria (cf. Grinn-Gofron 2008). Detailed report reflecting the entire airborne fungal spores and fragments is being prepared for subsequent publication. Because there are very few meteorological stations in the state, the meteorological data were obtained from the weather network Statistics Enugu State, Nigeria, located in Enugu South. The station is located at a range of 20 to 60 km to the nine sampling sites. The meteorological parameters utilised in the assessment of the effects of weather conditions on the monthly airborne fungal spores were mean relative humidity, mean rainfall, mean wind speed, mean air temperature, mean light intensity and mean wind direction. The statistical correlation between the monthly fungal spore abundance and mean monthly meteorological factors ( $n = 12$ ) was calculated using Spearman's

Rho correlation coefficient method in the SPSS program version 16.0.

## Results

The majority of the selected fungal taxa belong to the anamorphic fungi, with the exception of *Ganoderma* (basidiospores) and *Ustilago* (teliospores). Of the 14 fungal spore types, 12 are members of the Ascomycota while the others, *Ganoderma* and *Ustilago*, belong to the Basidiomycota producing basidiospores and teliospores, respectively. The monthly and cumulative annual totals of the concentration of 14 selected spore types are shown in Table II. Spores were present in high quantity throughout the rainy and late rainy seasons with the highest levels reached in June–August and October–December. The most frequent and abundantly recorded fungal spores among the selected spore types were those of *Nigrospora*, *Endophragmiella*, *Ustilago*, *Botryodiplodia*, *Pithomyces* and *Curvularia*. Of the 14 spore types, the maximum levels for *Alternaria*, *Endophragmiella*, *Ganoderma*, *Nigrospora* and *Pithomyces* were recorded in July; *Botryodiplodia*, *Ustilago* and *Gliomastix* attained their peaks in June; *Curvularia* and *Drechslera* type were in March, while *Spiegazzinia*, *Tetraploa*, *Corynespora* and *Sporidesmium* were in October and December, respectively (Table II).

Table II. Annual and monthly records of the abundance (cm<sup>2</sup>/month/year) of selected spore types in the southern part of Enugu, Nigeria (2005–2006).

| Period<br>Taxa         | March       | April  | May    | June          | July          | August | September | October    | November | December    | January | February | Total   |
|------------------------|-------------|--------|--------|---------------|---------------|--------|-----------|------------|----------|-------------|---------|----------|---------|
| <i>Alternaria</i>      | 23          | 109    | 128    | 86            | <b>253</b>    | 0      | 27        | 192        | 124      | 206         | 28      | 142      | 1318    |
| <i>Corynespora</i>     | 100         | 302    | 517    | 759           | 932           | 217    | 181       | 399        | 808      | <b>2374</b> | 511     | 245      | 7345    |
| <i>Curvularia</i>      | <b>3534</b> | 1006   | 1350   | 1528          | 306           | 325    | 866       | 3468       | 3294     | 2569        | 1770    | 1499     | 21 515  |
| <i>Drechslera</i> type | <b>286</b>  | 93     | 187    | 108           | 75            | 229    | 89        | 149        | 95       | 231         | 91      | 6        | 1639    |
| <i>Endophragmiella</i> | 161         | 990    | 3473   | 10 706        | <b>27 483</b> | 5642   | 5952      | 23 572     | 11 586   | 6371        | 1478    | 482      | 97 896  |
| <i>Botryodiplodia</i>  | 354         | 2763   | 1560   | <b>14 204</b> | 1136          | 322    | 888       | 1637       | 704      | 322         | 207     | 527      | 24 624  |
| <i>Ganoderma</i>       | 13          | 47     | 124    | 84            | <b>528</b>    | 2      | 44        | 61         | 51       | 177         | 0       | 8        | 1139    |
| <i>Gliomasrix</i>      | 47          | 66     | 156    | <b>573</b>    | 63            | 22     | 60        | 177        | 158      | 120         | 55      | 0        | 1497    |
| <i>Nigrospora</i>      | 2026        | 4456   | 5244   | 13 836        | <b>32 118</b> | 17 556 | 14 011    | 9630       | 10 727   | 11 831      | 7941    | 5622     | 134 998 |
| <i>Pihomyces</i>       | 221         | 440    | 1205   | 2838          | <b>3587</b>   | 1371   | 967       | 2688       | 1968     | 1024        | 474     | 442      | 17 225  |
| <i>Spegazzinia</i>     | 131         | 60     | 122    | 79            | 97            | 18     | 184       | <b>530</b> | 263      | 67          | 98      | 17       | 1666    |
| <i>Sporidesmium</i>    | 0           | 84     | 68     | 74            | 6             | 0      | 29        | 172        | 165      | <b>229</b>  | 88      | 214      | 1129    |
| <i>Teraploa</i>        | 130         | 229    | 261    | 225           | 117           | 449    | 142       | <b>476</b> | 333      | 363         | 200     | 96       | 3021    |
| <i>Ustilago</i>        | 769         | 928    | 2023   | <b>8351</b>   | 5005          | 1174   | 1391      | 6458       | 3323     | 2994        | 1201    | 1744     | 35 361  |
| Total                  | 7795        | 11 573 | 16 418 | 53 451        | 71 706        | 27 327 | 24 831    | 49 609     | 33 599   | 28 878      | 14 142  | 11 044   |         |
| %                      | 2.2         | 3.3    | 4.6    | 15.2          | 20.4          | 7.8    | 7.1       | 14.2       | 9.6      | 8.2         | 4.0     | 3.2      |         |

Note: Bold values indicate the months of the highest abundance of each fungal spore type.

Table III. Spore abundance (cm<sup>2</sup>/year) at the nine study sites in the southern part of Enugu, Nigeria (2005–2006).

| Spore type             | UNTH Inuku<br>Ozalla | Iwollo<br>II | Ngwo Express<br>Junction | Oji River Express<br>Junction | Mgbowo<br>Junction | Iwollo<br>I | Oji River<br>Park | Agbani General<br>Hospital | Awgu<br>Village | Total   | %    |
|------------------------|----------------------|--------------|--------------------------|-------------------------------|--------------------|-------------|-------------------|----------------------------|-----------------|---------|------|
| <i>Alternaria</i>      | 96                   | 4            | 52                       | 64                            | 759                | 183         | 14                | 64                         | 82              | 1318    | 0.4  |
| <i>Corynespora</i>     | 935                  | 98           | 136                      | 1053                          | 1835               | 1936        | 204               | 623                        | 525             | 7345    | 2.1  |
| <i>Curvularia</i>      | 3146                 | 284          | 255                      | 1666                          | 3226               | 10 810      | 327               | 1235                       | 566             | 21 515  | 6.1  |
| <i>Drechslera</i> type | 162                  | 45           | 50                       | 142                           | 601                | 446         | 56                | 101                        | 36              | 1639    | 0.5  |
| <i>Endophragmiella</i> | 25 489               | 1236         | 2133                     | 5664                          | 28 885             | 26 893      | 984               | 4900                       | 1712            | 97 896  | 27.9 |
| <i>Botryodiplodia</i>  | 2110                 | 113          | 339                      | 18738                         | 1336               | 687         | 161               | 743                        | 397             | 24 624  | 7.0  |
| <i>Ganoderma</i>       | 213                  | 30           | 31                       | 83                            | 581                | 145         | 23                | 24                         | 9               | 1139    | 0.3  |
| <i>Gliomasrix</i>      | 139                  | 25           | 37                       | 63                            | 685                | 259         | 39                | 156                        | 94              | 1497    | 0.4  |
| <i>Nigrospora</i>      | 16 560               | 1096         | 3900                     | 11 402                        | 72 153             | 15 952      | 1221              | 9317                       | 3397            | 134 998 | 38.5 |
| <i>Pihomyces</i>       | 2356                 | 85           | 345                      | 1967                          | 8509               | 2783        | 167               | 613                        | 400             | 17 225  | 4.9  |
| <i>Spegazzinia</i>     | 175                  | 23           | 80                       | 95                            | 308                | 848         | 12                | 101                        | 24              | 1666    | 0.5  |
| <i>Sporidesmium</i>    | 89                   | 31           | 16                       | 77                            | 244                | 560         | 61                | 15                         | 36              | 1129    | 0.3  |
| <i>Teraploa</i>        | 507                  | 139          | 375                      | 304                           | 867                | 417         | 152               | 139                        | 121             | 3021    | 0.9  |
| <i>Ustilago</i>        | 4234                 | 413          | 2481                     | 7962                          | 12 783             | 3000        | 727               | 2622                       | 1139            | 35 361  | 10.1 |
| Total                  | 56 211               | 3622         | 10 230                   | 49 280                        | 132 772            | 64 919      | 4148              | 20 653                     | 8538            |         |      |
| %                      | 16.0                 | 1.0          | 2.3                      | 14.1                          | 37.9               | 18.5        | 1.2               | 5.9                        | 2.4             |         |      |

The period with the highest frequency and maximum occurrence of the selected spore types were in October (*Spegazzinia* and *Tetraploa*); June (*Botryodiplodia*, *Ustilago* and *Gliomastix*) and July (*Nigrospora*, *Endophragmiella*, *Pithomyces*, *Ganoderma* and *Alternaria*) (Table II). The annual total was highest for six fungal spore types and this occurred mostly in March, June and July (Table II).

With respect to the locations, the results showed that there were differences in the amount of fungal spores at the sites (Table III). The highest percentage (37.9%) fungal spores was recorded in Mgbowo Junction, followed by Iwollo I (18.5%) and UNTH Ituku Ozalla (16.0%), while Oji River Park (1.2%) and Iwollo II (1.0%) had the lowest percentages (Table III). The spores of *Nigrospora* dominated virtually in all the locations, constituting 38.5% of the total spores of the selected spore types. Other dominant spore types from the nine sites were *Endophragmiella* (27.9%), *Ustilago* (10.1%), *Botryodiplodia* (7.0%), *Drechslera* type (6.1%) and *Pithomyces* (4.9%) (Table III).

Spearman's correlation analysis was performed to ascertain, which meteorological factors were related with the highest numbers of fungal spores. The meteorological data used included rainfall, relative humidity, temperature, light intensity, wind velocity and wind direction. These variables correlated strongly with the occurrence of many of the selected fungal spore types. The amount of the airborne spores of the genera of *Curvularia* and *Sporidesmium* showed significant and negative correlation ( $n = 12$ ,  $P < 0.05$ ) with relative humidity, while *Nigrospora*

was significant ( $n = 12$ ,  $P < 0.05$ ) and positively correlated, while others were not significantly correlated (Table IV). The results also showed that only the amounts of *Endophragmiella* ( $n = 12$ ,  $P < 0.05$ ), *Nigrospora* ( $n = 12$ ,  $P < 0.01$ ) and *Pithomyces* ( $n = 12$ ,  $P < 0.05$ ) spores were significant and negatively correlated with temperature. Of the 14 fungal spore types, only the *Nigrospora* spores ( $n = 12$ ,  $P < 0.01$ ) were significantly and negatively correlated with light intensity. Similarly, only the spores of *Sporidesmium* were significantly ( $n = 12$ ,  $P < 0.05$ ) and positively correlated with wind velocity. There was no statistically significant correlation between the spore types of *Alternaria*, *Corynespora*, *Drechslera* type, *Botryodiplodia*, *Ganoderma*, *Gliomastix*, *Spegazzinia*, *Tetraploa* and *Ustilago*, and all the weather parameters tested.

It was observed that rainfall and wind direction had no significant correlation with any of the selected spore types. It is important to note that in spite of the high amounts of the spore types of *Ustilago* and *Botryodiplodia*, there was no significant correlation of these spore types with any of the meteorological factors. Airborne fungal spores occurred throughout the whole season in southern part of Enugu. The minimum amount of fungal spores occurred in the late dry season (January–April) while the maximum amounts occurred in the rainy season (May–October) to early dry season (November–December). *Nigrospora* was the most frequently recorded taxon with monthly maximum amounts in June–September, while the spores were lowest in March and April. The maximum amounts of most other spore types occurred in June and July (Table II).

Table IV. Spearman's correlation analysis of fungal spore abundance ( $\text{cm}^2/\text{year}$ ) against meteorological factors in the southern part of Enugu, Nigeria.

| Fungi                  | Rainfall (mm) | Relative humidity (%) | Temperature ( $^{\circ}\text{C}$ ) | Light intensity ( $\text{W}/\text{m}^2$ ) | Wind velocity (m/s) | Wind direction (deg) |
|------------------------|---------------|-----------------------|------------------------------------|-------------------------------------------|---------------------|----------------------|
| <i>Alternaria</i>      | -0.308        | -0.224                | 0.056                              | 0.189                                     | 0.315               | -0.189               |
| <i>Corynespora</i>     | -0.182        | -0.112                | -0.168                             | 0.035                                     | 0.301               | -0.329               |
| <i>Curvularia</i>      | -0.350        | -0.580*               | 0.559                              | 0.490                                     | 0.168               | -0.238               |
| <i>Drechslera</i> type | 0.126         | 0.042                 | 0.112                              | 0.301                                     | -0.357              | 0.007                |
| <i>Edophragmiella</i>  | 0.399         | 0.503                 | -0.636*                            | -0.427                                    | -0.308              | 0.469                |
| <i>Botryodiplodia</i>  | 0.497         | 0.403                 | -0.049                             | 0.217                                     | -0.063              | 0.336                |
| <i>Ganoderma</i>       | 0.042         | 0.224                 | -0.161                             | 0.182                                     | -0.098              | 0.098                |
| <i>Gliomastix</i>      | 0.350         | 0.196                 | -0.112                             | 0.210                                     | 0.063               | 0.105                |
| <i>Nigrospora</i>      | 0.406         | 0.657*                | -0.888**                           | -0.846**                                  | -0.455              | 0.531                |
| <i>Pithomyces</i>      | 0.490         | 0.573                 | -0.685*                            | -0.420                                    | -0.357              | 0.483                |
| <i>Spegazzinia</i>     | 0.168         | 0.140                 | -0.007                             | 0.126                                     | -0.259              | 0.392                |
| <i>Sporidesmium</i>    | -0.403        | -0.630*               | 0.340                              | 0.231                                     | 0.746**             | -0.508               |
| <i>Tetraploa</i>       | 0.503         | 0.245                 | -0.238                             | -0.014                                    | -0.098              | -0.098               |
| <i>Ustilago</i>        | 0.182         | 0.196                 | -0.357                             | -0.154                                    | 0.000               | 0.252                |

\*Significant =  $P < 0.05$ ; \*\*highly significant =  $P < 0.01$

## Discussion

This study presents the fungal spore content of 14 selected spore types in the south-eastern part of Enugu to determine the factors that influence their occurrence in the atmosphere. Considering the importance of fungal spores in allergic reactions, indicators of the extent of atmospheric bio-pollution and many crop failures, a better understanding of their distribution becomes pertinent for both human health and crop management (Sanchez & Bush 2001; Cashel et al. 2004; Zain 2011; Khan & Karuppaiyil 2012).

The results of this study are in agreement with previous studies on the presence of aerobiological particles in the atmosphere of Nigeria (Agwu et al. 2004; Njokuocha & Agwu 2007; Essien et al. 2013). Although these authors focussed on the determination of the diversity and abundance of fungal spores, the present analysis is also concerned with the influence of meteorological factors on airborne fungal spores of the selected genera. The selection of the 14 fungal taxa was arbitrary and does not suggest that they are the most dominant airspora in the area. They were selected on the basis of their high frequency and abundance, which has been confirmed by other studies (Khandelwal 1988; Njokuocha & Osayi 2005). The period of maximum fungal spore occurrence of most taxa occurred in June, July and October. Similar findings have been reported in previous studies in Nsukka, Nigeria (Agwu et al. 2004; Njokuocha & Agwu 2007). Of the spore types under study, the most frequently recorded spore types were *Nigrospora*, *Endophragmiella*, *Ustilago*, *Botryodiplodia*, *Pithomyces* and *Curvularia*. They occurred most frequently in the rainy season to early dry season (cf. Royes 1987; Khandelwal 1988). The variation in seasonal abundance may be attributed to the mesophilic and psychrotolerant nature of the different fungi that affect their development and peak of sporulation (Gravesen 1979). Similar fungal spore types have been recorded in high abundance by Hurtado and Riegler-Goihman (1987), Khandelwal (1988), Agwu et al. (2004) and Njokuocha and Osayi (2005). The prevalence of such high diversity and abundance of spores in the air is one of the causes of human allergies and exacerbation of respiratory problems (Frankland 1987; Chakraborty et al. 2001; Sanchez & Bush 2001; Damialis & Gioulekas 2006; Tang 2009). The high record of these spore types may be attributed to the warm and wet conditions as well as the host vegetation and other environmental variables prevailing in the area.

At the various locations, there was considerable variation in the amount of the selected fungal spore types. This variation may depend on the differences in

local microclimatic conditions and/or agricultural and other land management practices in the areas. In the Awgu Express Junction, where the highest number of fungal spores was recorded, the topography supports different vegetation subtypes ranging from relic forests to open wooded grassland and large acres of farmlands on both the lowland and upland areas. According to Stepalska and Wolek (2005), high fungal spore concentration may be related to the maturing and senescence of tree foliage, grasses, types of crops and other human activities. Similarly, other locations that had high numbers of fungal spores (Iwollo II, UNTH Ituku Ozalla and Oji River Express Junction) may be attributed to the nature of vegetation heterogeneity and type of litter, which may favour the growth of fungi during favourable seasons.

Among the fungi genera selected, *Nigrospora* had the highest monthly levels of fungal spores recorded. *Nigrospora* is mitosporic, cosmopolitan and wet-air spora whose spores are abundant in warm climatic regions. It grows commonly in decaying plant materials and has been identified as an aeroallergen (Chakraborty et al. 2001; Chaturvedi & Chaturvedi 2013; Ianovici et al. 2013). Some pathogenic species have been implicated as the cause of sheath rot of rice and black end diseases of cereals. The positive and significant correlation between airborne *Nigrospora* spores and relative humidity and the significant and negative correlation with temperature and light intensity suggests why the spores were recorded in high abundance during the rainy to early dry seasons. The relationship between relative humidity and temperature has been reported as among the most important factors implicated in the release and dispersal of fungal spores (Prince & Meyer 1976; Herrera & Zaldivar 1997), particularly members of the wet-air spora. Since wet and humid conditions encourage decomposition of organic materials on which *Nigrospora* thrives, such condition may have provided suitable environment for its growth and consequently lead in the occurrence of fungal spores during the rainy season (cf. Adhikari et al. 2004). The high abundance of this spore type in the atmosphere has been observed as a common trend in Nigeria (Agwu et al. 2004; Njokuocha & Agwu 2007; Essien et al. 2013). This finding, however, is at variance with most reports in Europe where *Cladosporium* and *Alternaria* have been observed as dominant airborne spore types (Sabariego et al. 2000; Troutt & Levetin 2001; Grinn-Gofron 2008; Ianovici et al. 2013).

*Endophragmiella* spore type was also recorded in high abundance compared to most other spore types and was next in abundance to *Nigrospora*. The frequencies were highest during the rainy season to

early dry season, June–October and November–December. The fact that the amounts of fungal spores were significantly and negatively correlated with temperature implies that low temperatures favour the rate of spore release. In other studies (Allitt 1986; Cashel et al. 2004), the high abundance of *Endophragmiella* spores has been recorded in the air during and after rainfall when humidity levels were sufficiently high (cf. Njokuocha & Agwu 2007). Relative humidity has also been reported to have a notable influence on the members of Ascomycetes and Basidiomycetes (Moore-Landecker 1990). In this study, it is possible that the spore release of *Endophragmiella* may have been triggered by rainfall and high relative humidity, which are normally preceded by low temperature. Such condition prevails in July in the region, where rainfall and high humidity result in low temperature, and this coincided with the month of highest frequency of the spores of *Endophragmiella*. The fungus is mostly a saprobe and anamorph wet-air spora (Gonianakis et al. 2005; Hjelmroos-Koski et al. 2006) belonging to the Ascomycota. It has been found to occur on rotten wood, dead branches and leaves (Ma et al. 2011) and there is no record of its allergenicity. Although airborne *Endophragmiella* spores may be present in other regions, it has not been recorded in low concentrations (Stepalska & Wolek 2005; Duong et al. 2008).

*Pithomyces*, a soil borne fungus that is ubiquitous and cosmopolitan in nature, has been regularly trapped in the air (Agwu et al. 2004; Njokuocha & Agwu 2007; Grinn-Gofron 2008; Essien et al. 2013). The number of spores was found to be significant and negatively correlated with temperature and occurred abundantly in the rainy season. This result is contrary to its classification as dry-air spora whose members occur abundantly in the atmosphere during conditions of low relative humidity and high wind speed (Hjelmroos 1993; Levetin 1995). Most members of this genus are saprophytes occurring in dead leaves of plants. Wet conditions in the rainy season may have promoted the growth of the fungus such that splashes of rainfall could have dislodged their spores leading to increase in their abundance and consequent washing down of the spores from the atmosphere (cf. Burge 1986). *Pithomyces* has been reported to be allergic and some members pathogenic, causing facial eczema in sheep due to the production of the alkaloid mycotoxin Sporidesmin (Di Menna et al. 2009). *Pithomyces chartarum* (Berk. et M.A. Curtis) M.B. Ellis has been reported to be pathogenic, causing leaf spot of wheat in Hungary, which resulted in serious leaf damage to the crop (Tóth et al. 2007).

Another dry-air spora, *Sporidesmium*, was found to show significant and negative correlation with relative humidity, and significant and positive correlation with wind velocity. The amount of fungal spores was higher during the dry season with peaks in December and February. This period is characterised by low relative humidity and high wind speeds due to the dry Northeast Trade Harmattan winds that influence the dispersal of particles in Nigeria. This makes it favourable for such dry-air spora like *Sporidesmium* to release abundant spores into the atmosphere (cf. Troutt & Levetin 2001). Available literature shows that they are anamorphic, mostly saprophytes, although some may be commensals or parasitic on lichens (Hjelmroos-Koski et al. 2006; Iturriaga et al. 2008).

Relative humidity, light intensity, temperature and wind velocity were the most important meteorological parameters associated with abundance of some of the spore types analysed in this study. This is comparable with the reports of Sabariego et al. (2000) and Grinn-Gofron (2008), where mean and low temperatures and relative humidity were observed as among the important factors leading to increase in fungal spores in the atmosphere. Also Hjelmroos (1993) and Stepalska and Wolek (2005) reported increase in spore record in the atmosphere with increase in relative humidity.

The strongest correlation factors during the periods of study were observed for *Curvularia*, *Sporidesmium* and *Nigrospora* with relative humidity; *Endophragmiella*, *Nigrospora* and *Pithomyces* with temperature; *Nigrospora* with light intensity; and *Sporidesmium* with wind velocity. Although the amounts of spores of some of the fungi in this study did not show any significant difference with the meteorological variables, most of them are pathogenic, causing serious diseases of crops leading to loss of harvest and are important aeroallergens. Some *Alternaria* species may be saprophytic, while others are serious plant pathogens causing such diseases as leaf spot, early blight of potato, tomato, pepper and Cruciferae, among others (Tsedaley 2014). It has been implicated in respiratory nasobronchial allergy, asthma and rhinitis in various parts of the world (Sanchez & Bush 2001; Wani et al. 2012). *Corynespora* is not only a potential aeroallergen, but some species have been reported to cause leaf spot disease of cucumber, sweet potato, soybean, tomato, cotton and many wild and cultivated plants (Jinji et al. 2007).

Another economically important fungi pathogen recorded is the rot fungi, *Botryodiplodia*, which causes rotting, dieback and canker in plants leading to major losses of mango, banana, cocoyam and yam (Twumasi et al. 2014). The basidiospores of *Ganoderma*, which are wet-air spora, occurred highest in

July, during the rainy season. The airborne spores have been associated with respiratory allergic diseases and are major diseases of palms in Indonesia. *Ganoderma boninense* Pat., a white rot fungus that causes basal stem and root rot of *Elaeis guineensis* A. Chev. and *Cocos nucifera* L. (Naher et al. 2013, 2015).

*Ustilago*, a smut fungus, which constitutes about 10.09% of the selected spore types, causes type 1 allergy in asthmatic and hay fever conditions. It is a major plant pathogen causing various diseases such as loose smut, black loose smut, covered smut and corn smut in most monocotyledonous plants (Ruiz-Herrera & Martínez-Espinoza 1998). Other spore types studied were those of *Drechslera* types, *Spegazzinia* and *Tetraploa*, some of which have evoked positive allergic reactions, especially *Drechslera* that causes type 1 allergy and fungal sinusitis. They are among the parasitic fungi that cause pre- and post-harvest losses of crops and their products (Mehrotra & Aggarwal 2003) such as *Drechslera*, which causes brown spot of rice (Chakraborty et al. 2001).

The exclusion of *Cladosporium*, a commonly reported airborne fungus in the selected spore types, was due to low amounts of fungal spores, which may be partly attributed to prevailing local environmental conditions. Secondly, the method of preparation of the samples, especially during centrifugation, fragile conidial chains could easily have disintegrated, thereby making identification and accurate spore count difficult under microscopic observation at a magnification of 400×. This may have led to the underestimation of its spore abundance. However, further studies of longer duration that will give a clearer picture of airborne spores are ongoing, for a one-year-study may not be sufficient for comprehensively predicting the abundance of fungal spore types and their relationship with meteorological parameters.

## Conclusion

The spores of the studied taxa were found to be present in the atmosphere in all the seasons and locations at varying amounts. The maximum number of spores of most taxa occurred between June and December (from mid rainy season to early dry season). In the 12 months of study of selected taxa in Enugu, east Nigeria, relative humidity, temperature, light intensity and wind velocity influenced significantly the abundance of some of the selected fungal spore types.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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