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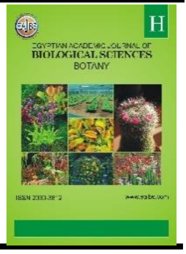

Distribution Modelling of the Moss *Funaria hygrometrica* Hedwig in Egypt

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ABSTRACT

Funaria hygrometrica Hedwig (Bryophyta, Funariaceae), a cosmopolitan moss, sporulates in most of its habitats. Its ecological variation in different phytogeographic territories of Egypt was studied as a selected case study. Statistical tests and the maximum entropy algorithm were used to achieve this aim. Moderate temperature and low precipitation were favourable conditions for the newly collected *F. hygrometrica* samples. The results of MaxEnt showed that the temperature of the coldest months and period of drought were the most affecting variables on the distribution of the species. The obtained distribution model of *F. hygrometrica* was accurate and informative. It showed the expansion of presently studied sampling areas as well as a probability for the presence of mosses in Wadi El-Gemmal in the southeast of Egypt.

INTRODUCTION

Mosses (Bryophyta) play important roles not only in natural ecosystems but also in scientific and applied systems (see Horn *et al.*, 2021). Mosses exist worldwide and are found in almost every environment (Mazzoni *et al.*, 2012). They have the ability to absorb and retain moisture (poikilohydric). They prefer humid areas but also survive either with little water on rocky and shallow substrates or submerged in lakes and rivers. Also, several species are xerophytic, i.e. adapted to the dry, hot desert (Glime, 2007).

The environmental conditions of Egypt do not fulfil the requirements of the majority of mosses. Egypt belongs to a hot desert-arid climate, based on the Köppen classification (Chen and Chen, 2013). But the Nile valley and Oases are influencing macro- and micro-habitats of the plants.

The, hitherto, known moss flora of Egypt, based on about four decades of study, is represented by 192 taxa (Khalil and Farag, 2018; Taha, 2020; Abou Salama et al., 2021), reported from 11 out of the 15 phytogeographical territories (El-Saadawi *et al.,* 2015) to which the country is divided. However, the production of a moss flora of Egypt has not been accomplished yet because of many reasons (El-Saadawi, 2019). Consequently, using prediction methods e.g. species distribution models (SDMs) is important to compensate for this shortage in our knowledge.

Species distribution models are algorithms and are widely used for analyzing relationships between environmental factors and habitats of a species (Elith and Leathwick, 2009). SDMs help in understanding the environmental (ecological) requirements and evaluating their quality for the species, and predicting the potential habitat of species (Yi *et*

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al., 2016). In addition, SDM estimates species' niches, and then projects those niches onto the landscape and informs decision-making in survey and conservation processes (see Guisan and Thuiller, 2005; Elith and Leathwick, 2009; Araújo *et al.,* 2011).

Studies published on modelling moss distribution are scarce. Most of them have used the maximum entropy algorithm (MaxEnt; Phillips *et al.,* 2006) only or combined with other algorithms. MaxEnt is a very flexible modelling algorithm (Elith *et al.,* 2006) even with low sample sizes (Pearson *et al.,* 2007) and depends on presence-only data (Phillips *et al.,* 2006). It works with the help of environmental covariant layers. The efficacy of default features of MaxEnt has been tested for many species and environmental conditions (Phillips and Dudík, 2008). It evaluates the produced maps concerning the habitat suitability of the species via a jackknife test (Yi *et al.,* 2016) and estimates model performance using Area Under Curve (AUC) of the receiver operating characteristics (ROC) (Pearson *et al.,* 2007).

Herein, the study represents the first investigation about the distribution modelling of mosses in Egypt. *Funaria hygrometrica* Hedwig (Bryophyta; Funariaceae), the most abundant moss in Egypt, is our model of study. It has been reported in 10 out of the 11 surveyed phytogeographical territories of the country (El-Saadawi *et al.,* 2015). It is a pioneer moss in natural habitats with high dispersal ability and fugitive life strategy (During, 1972). In general, the various populations of *F. hygrometrica* strongly showed the presence of climatological (thermal) ecological races within the species (Dietert, 1980).

This work aimed to statistically investigate the ecological variations of *F. hygrometrica* through the major part of its spatial environmental ranges and habitat diversity in Egypt and to determine the bioclimatic variables affecting distribution via species distribution modelling. The work also aimed to Investigate the ability to use this species for predicting the habitats suitable for mosses in Egypt.

MATERIALS AND METHODS

Plant Materials:

Twenty-five samples of *F. hygrometrica* were collected from northern to southern parts of Egypt to represent seven out of 11 phytogeographical territories in which mosses were surveyed in the country (Table 1). The distribution of sampling sites is clearly shown in figure 1. The sites include Kafr El-Shaikh, Al Qalyubia, Beny Suef, Menia, Asuit and Aswan around the Nile valley, while Cairo, Ismailia, Suez, and Al-Wadi Al-Jadid away from the Nile valley.

Identification of the samples was confirmed by matching with herbarium samples at CAIA and/or with available moss floras and other published works. A part of each sample was preserved in the CAIA herbarium-Bryophytes section under the herbarium names (CAIA-Fh-201- CAIA- Fh-225) (Table 1).

The materials include also old herbarium samples of *F. hygrometrica* (about 200 samples), kept at CAIA. They were revised their collection data. These samples were collected in the period 1979 to 1987 from 10 phytogeographic territories. Unfortunately, GPS data for these old samples are absent on envelopes (Table 2), but only the general locality was reported e.g., Benha in Al Qalyubia and El-Galaa bridge in Ismailia. These data of governorates were used only for confirming the quality of the distribution model.

Table 1. Data (Herbarium number, location, habitat, date of collection, Longitude, latitude and phytogeographic territory (Ph.T.)) of the 25 recently collected *Funaria hygrometrica* samples.

No.	Herbarium No.	Location	Habitat	Date	Long.	Lat.	Ph.T.
1	CAIA-Fh-201	Kafr El-Shaikh-Qilin	On soil beside water basin	4/2018	30.86	31.04	Nd
2	CAIA-Fh-202	Al Qalyubia-Al Khankah	On mud below water pot	3/2018	31.37	30.23	Nd
3	CAIA-Fh-203	Cairo-Abbassia	On cement, below water tap	3/2017	31.28	30.08	Cai
4	CAIA-Fh-204	Cairo-Ain Shams	on mud below a broken drainage pipe	5/2017	31.35	30.14	Cai
5	CAIA-Fh-205	Cairo-Kasr Al-Suez- el garage	On a thin film of mud, on a vertical wall	5/2017	31.36	30.13	Cai
6	CAIA-Fh-206	Cairo-Kasr Al-Suez- el garage	On a thin film of mud, on a vertical wall	4/2018	31.36	30.13	Cai
7	CAIA-Fh-207	Cairo-Misr Al-gededa	On soil below a water pot	5/2016	31.32	30.09	Cai
8	CAIA-Fh-208	Beny Suef-Bany 3day station	On limestone inside a drainage canal	5/2017	31.17	29.19	Nv
9	CAIA-Fh-209	Beny Suef-Tana Bani Malu	On cement of a water basin, near a water pump	5/2017	31.01	29.01	Nv
10	CAIA-Fh-210	Beny Suef-El-Wasta city	On cement of a dry irrigation basin, sunny area	2/2015	31.20	29.35	Nv
11	CAIA-Fh-211	Beny Suef-Bahns manorial	On limestone inside a dry drainage canal, sunny area	4/2015	31.26	29.44	Nv
12	CAIA-Fh-212	Beny Suef-El-Wasta, Emn El-Aroos	On cement, outside a dry basin, in shade of higher plants	4/2015	31.25	29.35	Nv
13	CAIA-Fh-213	Wadi El Jadid-Frafra-Abu Mingar	On rocks, dry area	2/2012	27.67	26.50	O
14	CAIA-Fh-214	Wadi El Jadid-Frafra-Frafra	On cement, inside a water basin	2/2012	27.96	27.06	O
15	CAIA-Fh-215	Menia-beginning of Menia-Aswan desert road	On a thin layer of mud on a wall of an irrigation canal, near a water pump	3/2016	30.77	28.11	Nv
16	CAIA-Fh-216	Menia-beginning of Menia-Aswan desert road	On a thin layer of mud, on a wall of an irrigation canal, near a water pump	3/2016	30.77	28.11	Nv
17	CAIA-Fh-217	Asuit-Markaz Al-Badari	On a water pot	1/2012	31.43	26.99	Nv
18	CAIA-Fh-218	Asuit-Markaz Al-Badari	On limestone of a water canal	1/2012	31.43	26.99	Nv
19	CAIA-Fh-219	Aswan-Marsa botanical island	On a cemented wall, near Berth ships beside the Nile	2/2017	32.90	24.09	Nn
20	CAIA-Fh-220	Aswan-Feryal Garden	On mud near crevices in a cemented wall	2/2017	32.89	24.08	Nn
21	CAIA-Fh-221	Ismailia -Al-tal Alkabier-ezbet mansour	On wet red brick wall of a water basin	12/2014	31.82	30.51	Di
22	CAIA-Fh-222	Ismailia-west Kantara-Abu Khalifa, Ezbet El Saaideh	On a thin layer of mud above a red brick wall of a water reservoir	12/2014	32.25	30.78	Di
23	CAIA-Fh-223	Ismailia -Ismailia city- Ein ghoseen village, Ezbet Elkarnak	On wet mud of a small water canal	2/2015	32.26	30.51	Di
24	CAIA-Fh-224	Ismailia-fayed city-Sarabiuom village	On a wet red brick wall, shaded area	12/2015	32.31	30.48	Di
25	CAIA-Fh-225	Suez-Wadi Hagoul	On sand beneath plants	3/2016	32.20	29.92	Dg

* **Cai:** Cairo area; **Dg:** Galala Desert; **Di:** Isthmic Desert; **Nd:** Nile Delta; **Nn:** Nile Nubia; **Nv:** Nile Valley; **O:** Oasis of Western Desert.

Table 2. Data of old *Funaria hygrometrica* samples kept at CAIA herbarium;

No.	Governorate	No. of H.S.*	Year of collection
1	Al Dakahlia	7	1979
2	Damietta	1	1980
3	Al Faiyum	14	1983
4	Al Gharbiyah	7	1979
5	Ismailia	65	1986-1987
6	Menofia	7	1979-1980
7	Al Qalyubia	21	1979-1980-1983
8	Ash Sharqia	72	1980-1985
9	South-Sinai	1	1983
10	Kafr El-Shaikh	2	1980

* No. of H.S.: number of available herbarium samples

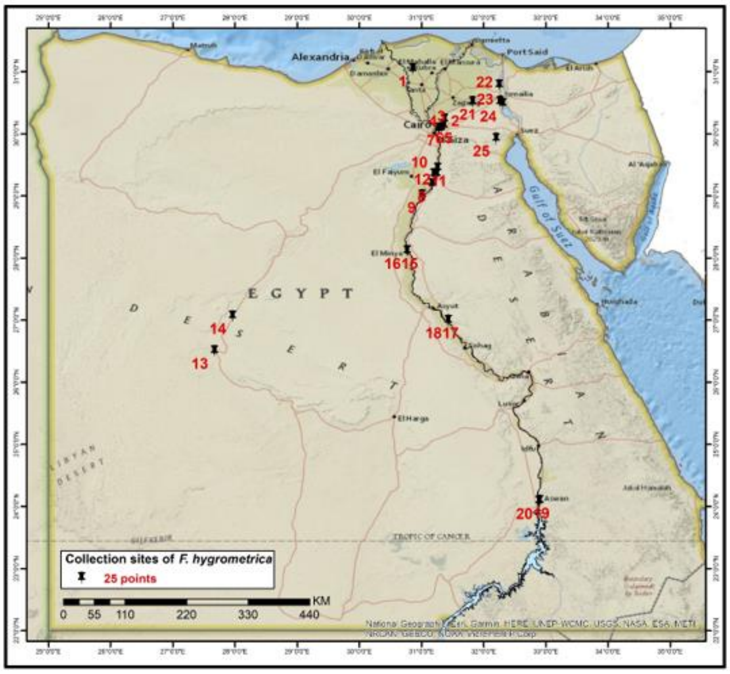

Fig. 1. Basemap of Egypt showing collection sites of the 25 newly collected samples of *Funaria hygrometrica*.

Ecological Data of *Funaria hygrometrica* and Statistical Analyses*:*

Nineteen bioclimatic variables (Bio 1-19) of the world with 30-sec resolution from Worldclim (Fick and Hijmans, 2017) were employed as environmental layers. Eleven variables represent bioclimatic data related to temperature i.e., Annual Mean Temperature (Bio1), Mean Diurnal Range (Mean of monthly temperature (max temp - min temp)) (Bio2), Isothermality ((Bio2/Bio7)×100) (Bio3), Temperature Seasonality (standard deviation ×100) (Bio4), Max Temperature of Warmest Month (Bio5), Min Temperature of Coldest Month (Bio6), Temperature Annual Range (Bio7), Mean Temperature of Wettest Quarter (BC8), Mean Temperature of Driest Quarter (Bio9), Mean Temperature of Warmest Quarter (Bio10), Mean Temperature of Coldest Quarter (Bio11).

The remaining eight variables represent precipitation bioclimatic data i.e., Annual Precipitation (Bio12), Precipitation of Wettest Month (Bio13), Precipitation of Driest Month (Bio14), Precipitation Seasonality (Coefficient of Variation) (Bio15), Precipitation of Wettest Quarter (Bio16), Precipitation of Driest Quarter (Bio17), Precipitation of Warmest Quarter (Bio18), Precipitation of Coldest Quarter (Bio19).

The bioclimatic data of the occurrences were extracted from 19 bioclimatic layers using Arc-GIS (10.2) toolbox via spatial analyst tool – extraction – sample. The extracted data of bioclimatic values of occurrences were subjected to descriptive and clustering statistical analyses using Excel 2016 and XlSTAT (v. 2020). Z-score is used to transform data before calculation of the correlations (Spearman) between bioclimatic variables. The agglomerative hierarchical clustering (AHC) of points was done to get the best clustering.

Distribution Modelling of Funaria Hygrometrica:

MaxEnt was used for mapping the distribution of *F. hygrometrica* and determining which bioclimatic variables have the highest impact on its distribution in Egypt. SDM depended on the 25 newly collected samples. The bioclimatic layers of Egypt were extracted from the layers of the World (Fick and Hijmans, 2017).

The parameters of MaxEnt were selected based on the previous publications of mosses modelling (Song *et al.*, 2015; Sandanov and Pisarenko, 2018; Pisarenko and Makunina, 2020) and the MaxEnt options (Merow *et al.*, 2013). They were: 'Auto features', percentage of test sample = 25%, the maximum number of iterations = 1000, subsample procedure with 15 replicates and the other settings as default.

The Accuracy Estimation of The Maxent Models:

Area Under Curve (AUC) was used to estimate model performance. In addition, MaxEnt calculates the percentage of contribution (CP) and permutation importance (PMI) of each bioclimatic variable. The variable importance for the species in the produced maps was evaluated by a jackknife test (Yi *et al.*, 2016) as the jackknife test determines the most useful environmental variable either through the determination of the highest gain when used in isolation (by itself) or that decreases the gain the most when it is omitted.

Two models were carried out at MaxEnt, using different sets of bioclimatic variables. The first model utilized 16 out of 19 bioclimatic variables, because bio14, bio17, bio18 had a value zero with all points. Bioclimatic variables, which had a high correlation between them (≥ 0.9 / ≤ -0.9) were removed to minimize the correlation between environmental variables at the second model. Output map files were then reloaded into Arc-GIS and the distribution was classified into 4 classes based on the species projected coverage: rare (0-0.249), moderate (0.25-0.599), high (0.60-0.849) and very high (0.85-1).

RESULTS

The newly collected samples of *F. hygrometrica* were found with sporophytes in most of their habitats at an altitudinal range of 0-300 a.s.l. The climatic conditions of habitats were high temperatures and rare precipitation (Table 3). The maximum temperature was 26.8-34.5 ˚C and the minimum temperature was 12.8-19 ˚C. The average precipitation was very low 1.4 mm, but some samples depended on the nearby source of water in their habitats i.e., irrigation water, or sewage water, or underground water.

Table 3. The altitude (Alt) and climatic data (maximum temperature (Tmax), minimum temperature (Tmin), precipitation (ppt.)) of the studied 25 *Funaria hygrometrica* samples. The five classes of samples are based on agglomerative hierarchical clustering (AHC) and corresponding phytogeographic territories (Ph.T.).

Herbarium No.	Alt.	Tmax	Tmin	ppt.	Class	Ph. T.
CAIA-Fh-201	4	26.8	13.2	5.7	3	Nv (Nd)
CAIA-Fh-202	16	28.0	14.4	2.0	4	Nv (Nd)
CAIA-Fh-203-204	36	28.3	14.6	1.6	4	Cai
CAIA-Fh-205	22	28.3	14.8	1.9	4	Cai
CAIA-Fh-206	22	28.3	14.8	1.9	4	Cai
CAIA-Fh-207	32	28.4	14.9	1.8	4	Cai
CAIA-Fh-208	25	29.4	13.8	0.6	3	Nv
CAIA-Fh-209	28	29.4	13.3	0.5	3	Nv
CAIA-Fh-210	26	29.3	14.2	0.7	3	Nv
CAIA-Fh-211	28	29.3	14.6	0.9	3	Nv
CAIA-Fh-212	34	29.3	14.4	0.8	3	Nv
CAIA-Fh-213	133	30.4	13.5	0.0	2	O
CAIA-Fh-214	72	30.0	13.2	0.2	2	O
CAIA-Fh-215-216	64	29.6	12.8	0.1	3	Nv
CAIA-Fh-217-218	60	30.5	15.0	0.2	3	Nv
CAIA-Fh-219	110	34.5	19.1	0.1	1	Nn
CAIA-Fh-220	110	34.5	19.1	0.1	1	Nn
CAIA-Fh-221	9	27.7	14.9	2.8	3	Nv (Di)
CAIA-Fh-222-223	2	27.3	15.9	3.8	5	Di
CAIA-Fh-224	8	28.4	15.9	2.3	5	Di
CAIA-Fh-225	295	27.4	14.7	2.0	3	Nv (Dg)

* **Cai:** Cairo area; **Dg:** Galala Desert; **Di:** Isthmic Desert; **Nd:** Nile Delta; **Nn:** Nile Nubia; **Nv:** Nile Valley; **O:** Oasis of the Nubian and the Libyan Desert.

Based on bioclimatic variables, the annual mean of temperature (Bio1) of sites of the collection is about 22 ˚C while the annual mean of precipitation (Bio12) is about 18.9 ±17.7 mm. The minimum temperature of the coldest month (Bio6) is around 7 ˚C and precipitation of the wettest quarter (Bio16) ranged from 0 to 44 mm between the samples. Precipitation of driest month (Bio14), precipitation of driest quarter (Bio17), and precipitation of warmest quarter (Bio18) had a value zero with all samples (Table 4).

Table 4. Descriptive data of bioclimatic variables (Bio1-Bio19) of *Funaria hygrometrica*

Bios	Min-Max	Median	Mean (±SD)
Bio1	19.9 - 26.7	6.8	22.1 ±1.7
Bio2	11.2 - 17.1	5.9	13.7 ±1.5
Bio3	44.7 - 48.9	4.2	47.3 ±1.2
Bio4	525 - 699.2	174.2	593.8 ±57.6
Bio5	31.5 - 41.7	10.2	36 ±2.6
Bio6	4.3 - 9.8	5.4	7.1 ±1.5
Bio7	24.8 – 35	10.2	28.9 ±3
Bio8	13.2 - 19.1	5.9	15.1 ±1.5
Bio9	18.8 – 28	9.2	25.3 ±3.3
Bio10	25.8 - 33.9	8.2	28.8 ±2.1
Bio11	13 - 17.6	4.6	14.3 ±1.2
Bio12	0 – 68	68	18.9 ±17.7
Bio13	0 – 18	18	4.5 ±4.3
Bio14	0 – 0	0	0 ±0
Bio15	0 - 92.8	92.8	53.8 ±25.2
Bio16	0 – 44	44	11.3 ±10.6
Bio17	0 – 0	0	0 ±0
Bio18	0 – 0	0	0 ±0
Bio19	0 – 44	44	11.1 ±10.6

The correlation analysis of bioclimatic variables showed a high correlation between them based on the bioclimatic data of studied samples (Table 5). As a result, only six moderate or non-correlated bioclimatic variables were selected i.e. bio1, bio3, bio6, bio8, bio9 and bio11. These variables were related to temperature only. They were used to cluster the samples via AHC as well as the second SDM.

Table 5. Correlation matrix (Spearman) of bioclimatic variables of the samples of *Funaria hygrometrica*.

Bios	bio1	bio2	bio3	bio4	bio5	bio6	bio7	bio8	bio9	bio10	bio11	bio12	bio13	bio15	bio16	bio19
bio1	**1.00**															
bio2	**0.66**	**1.00**														
bio3	0.18	-0.04	**1.00**													
bio4	**0.63**	**0.96**	-0.16	**1.00**												
bio5	**0.73**	**0.96**	-0.15	**0.95**	**1.00**											
bio6	0.06	**-0.49**	0.06	**-0.47**	-0.33	**1.00**										
bio7	**0.66**	**0.99**	-0.08	**0.97**	**0.97**	**-0.47**	**1.00**									
bio8	**0.45**	0.13	-0.15	0.20	0.24	**0.48**	0.17	**1.00**								
bio9	-0.26	**-0.58**	0.30	**-0.59**	**-0.55**	0.23	**-0.57**	-0.36	**1.00**							
bio10	**0.82**	**0.92**	-0.17	**0.92**	**0.96**	-0.30	**0.93**	0.26	**-0.52**	**1.00**						
bio11	**0.57**	-0.09	0.32	-0.12	0.05	**0.79**	-0.06	**0.61**	0.15	0.11	**1.00**					
bio12	**-0.73**	**-0.97**	0.16	**-0.94**	**-0.98**	0.33	**-0.97**	-0.24	**0.56**	**-0.95**	-0.04	**1.00**				
bio13	**-0.69**	**-0.96**	0.19	**-0.95**	**-0.98**	0.35	**-0.97**	-0.18	**0.55**	**-0.95**	0.01	**0.99**	**1.00**			
bio15	**-0.60**	**-0.93**	0.25	**-0.95**	**-0.91**	0.38	**-0.94**	-0.27	**0.63**	**-0.89**	0.07	**0.94**	**0.94**	**1.00**		
bio16	**-0.67**	**-0.95**	0.25	**-0.93**	**-0.96**	0.33	**-0.96**	-0.25	**0.62**	**-0.93**	-0.02	**0.98**	**0.97**	**0.95**	**1.00**	
bio19	**-0.66**	**-0.94**	0.25	**-0.93**	**-0.96**	0.33	**-0.96**	-0.25	**0.64**	**-0.93**	-0.01	**0.98**	**0.97**	**0.94**	**1.00**	**1.00**

Values in bold are different from 0 with a significance level alpha=0.05

* The grey columns represent bioclimatic variables, which are highly correlated with the other variables and were removed from further analyses.

The samples were divided into 5 groups based on AHC (Table 3 & Fig. 2). The within-group variation and the variation between all groups are 13.9% and 86.1%, respectively. The distribution of these 5 groups agreed with the phytogeographical regions of Egypt. The exception case was the expansion of the territory of the Nile valley to include samples from the Nile delta (CAIA-Fh-201 and CAIA-Fh-202), Isthmic Desert (CAIA-Fh-221) and Galala desert (CAIA-Fh-225) (Table 3). In general, this indicated the heterogeneity of ecological data between the samples under study and its validity to construct SDM all over Egypt.

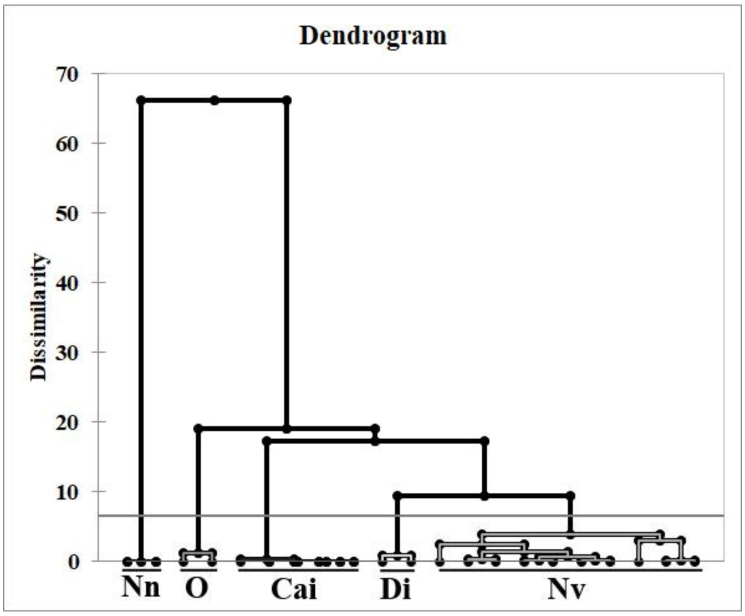

Fig. 2. The agglomerative hierarchical clustering of the 25 samples of *Funaria hygrometrica* in five phytogeographic territories based on six bioclimatic variables (bio1, bio3, bio6, bio8, bio9 and bio11).

Cai: Cairo area; **Di:** Isthmic Desert; **Nn:** Nile Nubia; **Nv:** Nile Valley; **O:** Oasis.

MaxEnt produced a good distribution model for *F. hygrometrica* according to the AUC statistic value. AUC training /AUC tests were about 0.94 / 0.83 with the two species distribution models of *F. hygrometrica*. It is distributed with high probability along the Nile River, its branches until Ismailia in the east, in oases, and at the Red Sea mountains in Egypt (Fig. 3 A, B). The probability decreases gradually towards the south of Egypt. Its absence below Aswan was supported by our observation through our fieldwork to the Toushke region. A rare probability of distribution in the west-Mediterranean coast, Lybian desert, and Sinai (Fig. 3 A, B).

The first SDM showed that Bio9, Bio10, and Bio18 were the main contributors. Bio5 and Bio3 were the most useful variables in the jackknife test. The second model utilized six bioclimatic variables (see above). The contribution percentages of Bio9, Bio1, and Bio3 were 50.3, 22.5, and 11.3, respectively, while permutation importance was high for all of them except Bio8. Based on the jackknife test, Bio9 and Bio1 had the most effects (Fig. 3, C, D).

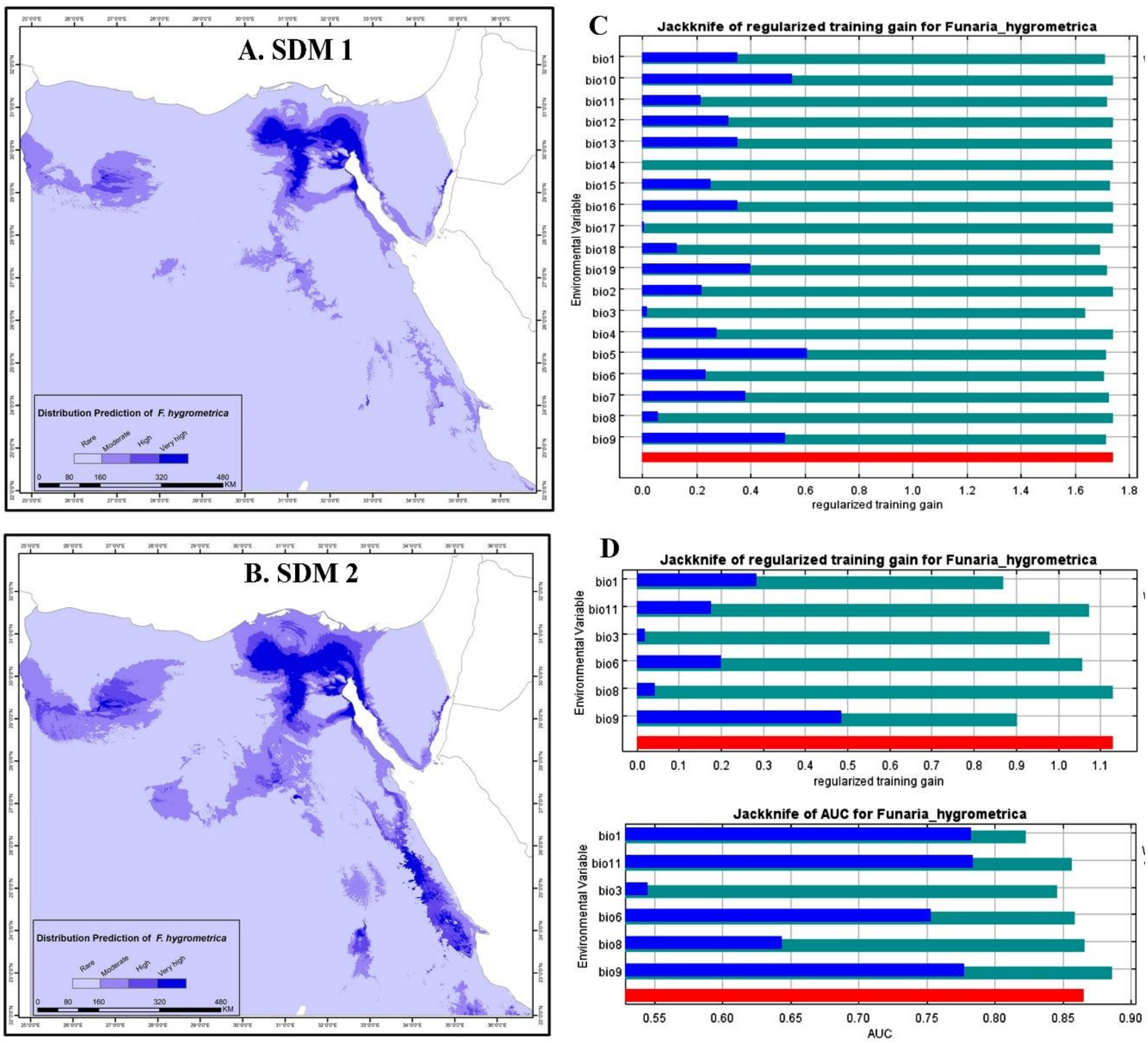

Fig. 3. The map of the SDM of *Funaria hygrometrica* in Egypt. A: The map of the first model is based on 16 bioclimatic variables. B: The map of the second model is based on 6 bioclimatic variables. C. The jackknife test of variable importance with the training samples of the first model. D. The jackknife test of variable importance with the training samples and AUC of the second model.

DISCUSSION

Funaria hygrometrica usually produces sporophytes with small, easily airborne spores (Magdy *et al.,* 2015), which are not restricted to geographical or political borders. Gabbas and Dormann (2017) mentioned that there is a possibility of the regional data could reflect the wide range of distribution of the taxon if heterogeneity were achieved between sampling locations. Here, the analysis of ecological variation of *F. hygrometrica* at the regional level (Egypt) could emphasize adapting ranges of the species, especially, the results showed heterogeneity and clustering of samples into five groups.

MaxEnt models of *F. hygrometrica* produced well-fit distribution over Egypt as AUC values were more than 0.90. AUC values of more than 0.75 indicate high fitting of the models (Mulieri and Patitucci 2019). The distribution model of *F. hygrometrica* at the level of Egypt was informative and accurate. The efficacy of distribution maps was confirmed by the agreement of distribution and probability with the locations and number of the previously old herbarium samples (see Table 2). For example, the highest records of herbarium samples were from Ash Sharqiyah and Ismailia and both showed a high probability of the presence of the species. Pisarenko and Makunina (2020) concluded that the accuracy of modelling at the regional level was better than the global level with the SDM of five mosses i.e., *Aulacomnium turgidum* (Wahlenb.) Schwägr., *Eurhynchium angustirete* (Broth.) T.J.Kop. *Jaffueliobryum latifolium* (Lindb. & Arnell) Ther., *Rhytidium rugosum* (Hedw.) Kindb., and *Stegonia latifolia* (Schwägr.) Venturi ex Broth.

Two models with different sets of bioclimatic variables were carried out because the correlations of variables could affect their contribution (Guillera-Arroita *et al.,* 2015). The bioclimatic variables Bio5, Bio10, and Bio18 were among the main contributors and effective variables at the first SDM, they have been avoided at the second model because of very high correlations between each other or with other variables. Bio5 and Bio10 were replaced by Bio1, which showed a moderate correlation.

SDM of *F. hygrometrica* in Egypt showed that Bio1, Bio9, and Bio11 were the determining variables of the distribution. we suggested that the importance of these bioclimatic variables returns to their effects in controlling the stages of gametangia formation and spore dispersal. The former occurs at low temperature and the latter carries on at drought (Nakosteen and Hughes, 1978; Dietert, 1980). The affecting bioclimatic variables vary between various species. *Didymodon* distributions of Tibet exhibited the high gains by Bio1, Bio6, Bio5, and Bio13 (Song *et al.,* 2015). The distribution of *Crossidium squamiferum* was affected by Bio4 and Bio8 (Sandanov and Pisarenko, 2018).

Herein, SDM showed expansion of the suitable areas of *F. hygrometrica* outside the collection areas toward the Siwa oasis, Nile Faiyum and the Red Sea. The latter may be a suitable habitat for mosses and a new promising area, especially the region of Wadi El-Gemmal, for a survey of moss flora in Egypt. The moss flora in this region has not been studied before. This agreed with a major assumption of SDMs, that when a random sample of species distribution is used, the probability of the presence of this species in an area shows its macroclimatic preference and not a sampling bias (Veloz, 2009; Phillips *et al.,* 2009; Mateo *et al.,* 2013).

Funaria hygrometrica could be a useful taxon to predict new niches for the presence of mosses in Egypt, its ability to be used alone as a model is not sufficient. This may return to two reasons. Firstly, although *F. hygrometrica* was collected from 10 phytogeographic regions, the habitats of Egypt represent a wide range of conditions. They were divided into 15 phytogeographical regions based on climatic and vegetation habitats (Tackholm, 1974; El-Hadidi and Fayed, 1994/95). Secondly, the relation of *F. hygrometrica* to disturbed habitats and human activities (Shaw *et al.,* 2003) may be causing disability to represent mosses, which depend on precipitation and/or at mountains such as the mosses of the Mediterranean coast, Sinai, and Gebal Alba.

Our further work will investigate molecular studies of the populations of different ecological groups for improving our understanding of the variation, adaptation, and diversity of species.

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ARABIC SUMMARY

نمذجة توزيع الحزاز القائم فيوناريا (*Funaria hygrometrica* Hedwig) فى مصر

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الحزاز القائم فيوناريا من الأنواع واسعة الإنتشار. لديه القدرة على التكاثر في معظم موائله. تم اختياره كنموذج لدراسة تباينه البيئي في بعض المناطق الجغرافية النباتية بمصر. لتحقيق الهدف من الدراسة تم استخدام الاختبارات الإحصائية وخوارزمية الانتروبيا القصوى (MaxEnt). وأوضحت النتائج أن درجات الحرارة المعتدلة والمعدل المنخفض لهطول الأمطار ظروفًا مواتية لعينات الفيوناريا التي تم جمعها حديثًا. وقد أظهرت نتائج MaxEnt أن درجة الحرارة بالشهور الباردة وفترة الجفاف تعتبر المتغيرات الموثرة على توزيع النوع. ونموذج التوزيع الذي تم الحصول عليه دقيقًا وغنيًا بالمعلومات. وقد أظهر نطاق أوسع لتوزيع النوع عن مناطق أخذ عينات الدراسة بالإضافة إلى احتمال وجود موائل جديدة لوجود الحزازيات القائمة في مصر كمنطقة وادي الجمال بجبال البحر الأحمر