ISSN: 2476-6909; ECOPERSIA . 2019;7(4):195-201

Predicting the Potential Distribution of Jujube (*Ziziphus jujuba* Mill.) in Iran

ARTICLE INFO

Article Type
Original Research

Authors
Moudi M.*[1] *PhD,*
Hosseinzadeh M.S.[1] *PhD*

How to cite this article
Moudi M, Hosseinzadeh M.S. Predicting the Potential Distribution of Jujube (Ziziphus jujuba Mill.) in Iran. ECOPERSIA . 2019;7(4):195-201.

[1]Biology Department, Science Faculty, University of Birjand, Birjand, Iran

***Correspondence**
Address: Biology Department, Science Faculty, University of Birjand, Birjand, Iran
Phone: +98 (56) 32202065
Fax: +98 (56) 32202065
maryammoudi@birjand.ac.ir

Article History
Received: March 9, 2019
Accepted: September 14, 2019
ePublished: December 21, 2019

ABSTRACT

Aims Species distribution models (SDMs) are predictive models for species' geographic distributions which are in association with environmental factors and presence of species. SDMs are important for a variety of applications in systematics, ecology, and conservation. The genus Ziziphus Mill. (Rhamnaceae) comprises six species in Iran including Z. spina-christi, Z. nummularia, Z. jujuba, Z. mauritiana, Z. lotus, and Z. oxyphylla. Out of which, Z. jujuba is a common species of the genus.
Materials and Methods In this study, 43 occurrences of Ziziphus jujuba were recorded and used in the maximum entropy distribution modeling approach (MaxEnt) with five environmental variables. Three important variables: bio6 (Min Temperature of Coldest Month, 24.3%), bio8 (Mean Temperature of Wettest Quarter, 23%), bio9 (Mean Temperature of Driest Quarter, 20.5%) include 67.8% of all percentage contribution in the final model.
Findings Slope, five temperate and two precipitation variables influenced our final model. The most suitable habitats are located in eastern Iran which completely corresponds to South Khorasan province and central Iran. Additionally, the species is distributed in northern Iran as well but our model doesn't show northern Iran as the most suitable habitat for Z. jujuba which probably related to the species has been cultivated in that place.
Conclusion Temperature is one of the most important factors in the distribution of Z. jujuba and it is compatible with that Jujube trees raise in arid and semiarid zones. However, the predictable habitats are distributed in central and eastern Iran which partly corresponds to South Khorasan province.

Keywords Species Distribution Model; Jujube; Temperature; South Khorasan; Environmental Factors

CITATION LINKS

[1] Predictive vegetation mapping: Geographic modelling ... [2] New developments in museum-based informatics ... [3] Geographic analysis of conservation ... [4] Novel methods improve prediction of species' distributions from occurrence ... [5] Maximum entropy modeling of species geographic ... [6] A statistical explanation of MaxEnt for ... [7] A review of methods for the assessment of prediction errors ... [8] Using niche-based models to improve ... [9] Flora of ... [10] Trees and shrubs of ... [11] Ziziphus jujube (ennab) of the middle east, food and ... [12] Aqueous extract of Ziziphus jujuba fruit attenuates glucose induced neurotoxicity in an in vitro model of diabetic ... [13] Jubanines F-J, cyclopeptide alkaloids from the roots ... [14] Medicinal and nutritional properties of Ziziphus ... [15] Review on ethnomedicinal uses, pharmacological activity ... [16] "Ziziphus jujuba": A red fruit with promising ... [17] Gastroprotective effect of aqueous stem bark extract of Ziziphus ... [18] Species distribution models applied to plant species selection in ... [19] Predicting species distribution: Offering more than simple ... [20] Study of genetic variation in Iranian Jujube ... [21] Chinese Jujube: Botany and ... [22] Ziziphus jujuba ... [23] Study of genetic diversity of Ziziphus jujuba ... [24] A study on genetic variation in Iranian Jujube ... [25] Grouping jujubes of Iran based on quantitative characteristics ... [26] Flora of ... [27] Very high resolution interpolated climate surfaces for ... [28] Incorporating classified dispersal assumptions in predictive distribution ... [29] AUC: A misleading measure of the performance of predictive ... [30] Insights into the area under the receiver operating characteristic curve ... [31] Evaluating presence-absence models in ... [32] New compounds from Zizyphus ... [33] Flora of the kingdom of Saudi ... [34] Anatomy-taxonomy of the genus Ziziphus in ... [35] Genetic diversity of Jujube (Ziziphus jujuba Mill.) germplasm based on vegetative and fruits physicochemical characteristics from Golestan province of ... [36] Identifying the genetic diversity, genetic structure and a core collection of Ziziphus jujuba ...

Introduction

Species distribution models (SDMs) are predictive models for species' geographic distributions which are in association with environmental factors and presence of species [1]. SDMs are important for a variety of applications in systematics, ecology, and conservation [2]. Therefore, SDMs can be used to fill these knowledge gaps by mapping potential distribution ranges and so identify sites at which searches are more promising than others and should be considered for conservation programs [3]. MaxEnt is an algorithm associated with species presence data that enables the construction of well-fitted predictive performance according to environmental and ecology data. Interestingly, it is considered one of the most efficient approaches for predicting species distribution models based on presence data.[4-6] However, testing is required to assess the predictive performance of the model. Hence, the most usual approach is to divide data into 'training' and 'test' datasets, thus creating relatively independent data for model testing [7, 8].

The genus Ziziphus Mill. (Rhamnaceae) is distributed in tropical Asia, Africa, and America and the temperate regions of both hemispheres with 50 species [9]. However, six species have been reported from Iran including *Z. spina-christi, Z. nummularia, Z. jujuba, Z. mauritiana, Z. lotus, and Z. oxyphylla* [10]. Out of which, *Z. jujuba* is a common species in this genus which is distributed in southern Europe and Asia, including Russia, India, the Middle East (especially Iran, Jordan, Lebanon, Palestine, Syria, and Egypt) and China [11-13]. It is a deciduous tree that grows very well in the Mediterranean climate and can tolerate heat and aridity.[11] This plant is also known as *Ziziphus vulgaris* Lam., *Rhamnus ziziphus* L., *Ziziphus sativa* Gaertn., and *Ziziphus zizyphus* (L.) Karsten around the globe. Besides, lageniformis, inermis, jujuba, and spinosa are among the different species of this plant, and *Ziziphus mauritiana* is another name for *Z. jujuba* Mill. This plant is known as Ennab and Annab in the Arabic and Persian languages, respectively [14]. The fruits are date-shaped and reddish-brown, purplish black when mature, with a sweet mucilaginous matter [11, 15]. It is widely used in traditional medicine as a laxative, blood purifier, a taste enhancer and treatment for fatigue, loss of appetite and diarrhea [11]. Some of the compounds isolated from the seeds of *Z. jujuba* exhibit significant pharmacological activities. The fruit comprises many bioactive compounds including triterpenic acids, flavonoids, cerebrosides, phenolic acids, tocopherol, carotene, and polysaccharides. The mixtures cause some health benefits, thus making it a healthy food choice and also as a therapeutic agent [16]. In Iran, it is frequently used to treat digestive disorders and gastric ulcers since Avicenna prescriptions and as an antitussive, laxative and hypotensive agent [17].

An expert on local flora usually constitutes the best option for plant species selection in most ecological restoration projects. A simple approach is to build a database of known distribution limits of species along environmental gradients and then to identify which species are suitable for the site to be restored by comparing local environmental conditions to the limiting values [18]. Ranking species is desirable for species selection in restoration projects and requires continuous habitat suitability estimations. Such estimations make up part of the output of predictive species distribution models (SDM), which relate field observations to environmental predictor variables [19]. *Z. jujuba* is a medicinal and an economically important plant in Iran, especially in South Khorasan). Jujube is the indigenous plants in Iran and mainly cultivated in Provinces of Khorasan, Golestan, Mazandaran, Gilan, Fars, Esfahan, Yazd, Kerman, Lorestan, Hamedan, Tehran, Qazvin, and Qom [20]. This species has been cultivated over large areas in the Old World [21] while some other species are cultivated on a more localized scale. However, all the jujubes have been relatively minor crops, although demand for their production remains steady in many parts of their original domestication [22]. In the case of SDM applied to plant species selection for ecological restoration, comparing model predictions to expert opinion may be especially useful. According to the high demand of Jujube production a medicinal and important plant not only in Iran but also in the world; therefore it is necessary to prepare a map of distribution zone of this species especially in Iran. Indeed, it helps us to find the best areas that have a high capacity to cultivate this species and produce more crops.

The aims of this study were to provide a comprehensive distribution map of *Z. jujuba*, and to identify the environmental variables associated with the predicted distribution of *Z. jujuba* using a maximum entropy distribution modeling approach.

Material and Methods

All records of *Z. jujuba* are compiled by our own fieldwork and literature as well [20, 23-26] (Table 1). Some of the data with exact locality names and no coordinates have been georeferenced using the global gazetteer 2.1 (http://www.fallingrain.com). A total of 43 locality records for *Z. jujuba* were gathered and used in the maximum entropy distribution modeling approach (MaxEnt 3.3.3). Twenty environmental variables, describing temperature, precipitation, seasonality, altitude, all with 30-arc-seconds resolution, were extracted from the Worldclim dataset (http://www.worldclim.org/) [27]. In addition, a slope layer was built from altitude layer information in ArcGIS 10 using the spatial analyst toolbox. First, correlations between all 21 environmental variables were measured with spearman's correlation coefficient in SPSS 16. The variables with a correlation coefficient>0.7 were excluded from species distribution modeling [28]. Then, 8 out of 21 environmental variables were chosen and used in this study (Tables 2, 3).

Convergence threshold and a maximum number of iterations were carried out by default (0.00001 and 500, respectively). However, cross-validation has been carried out to evaluate the predictive performance of the model. Jackknife test was used to produce estimates of the average contribution and response of each variable to the model. Our model was tested with "area" under the receiver-operating characteristic (ROC) curve (AUC) that has been used widely in analyzing species' distribution models and measures the ability of a model to distinguish between sites where a species is 'present' versus 'absent' [4, 5]. Some studies believe that this is not a standard scale to assess the performance of modeling although using the metric parameter, AUC, together with ROC plat are more suitable to provide information about the spatial distribution [29, 30]. Models with AUC=0.5 indicate a performance equivalent to random; AUC>0.7 indicates useful performance, AUC>0.8 indicates good performance, and AUC≥0.9 indicates excellent performance [31].

Table 1) Point localities in this study

	Distribution regions	Latitude	Longitude	References
1	Algur, South Khorasan	33.08	59.35	This study
2	Asfij, South Khorasan	32.56	59.54	This study
3	Doroh, South Khorasan	32.29	60.5	This study
4	Kangan, South Khorasan	32.68	5987	This study
5	Dorokhsh, South Khorasan	33.16	59.71	This study
6	Nooghab, South Khorasan	33.26	59.51	This study
7	Gazik, South Khorasan	33.03	59.48	This study
8	Geyuk, South Khorasan	32.79	59.12	This study
9	Kashook, South Khorasan	32.41	59.16	This study
10	Tajnud, South Khorasan	33.31	60.25	This study
11	Arabkhaneh, South Khorasan	32.18	59.52	This study
12	Koohpayeh, Esfahan	32.71	52.44	This study
13	Ardestan, Esfahan	33.38	52.37	This study
14	Shahreza, Esfahan	32.01	51.87	This study
15	Bayaziyeh, Esfahan	33.33	55.1	This study
16	Kalaleh, Golestan	37.38	55.49	[26]
17	Qom, Qom	34.64	50.88	This study
18	Moqam Sari, Mazandaran	36.6	53.08	This study
19	Juybar, Mazandaran	36.64	52.91	This study
20	Kazeroun, Fars	29.62	51.65	This study
21	Anbarestan, Razavi Khorasan	36.37	57.84	This study
22	Jafarabad, Qom	34.78	50.57	[24]
23	Jannatabad,Qom	34.51	51.07	[24]
24	Kam Chenar, Qom	34.65	50.47	[24]
25	Kasva, Qom	34.73	50.18	[24]
26	Kalagh neshin, Qom	34.69	50.43	[24]
27	Ghazi Olya, Qom	34.54	50.48	[24]
28	Behshahr, Mazandaran	36.69	53.55	[24]
29	Hamidabad- e- Sari, Mazandaran	36.77	53.1	[24]
30	Sari, Mazandaran	36.56	53.06	[23]
31	Natanz, Esfahan	33.51	51.92	[24]
32	Pudeh, Esfahan	31.12	51.67	[20, 24]
33	Niasar- e- Kashan, Esfahan	33.97	51.15	[20, 24]
34	Nowdan, Fars	29.8	51.69	[24]
35	Dashte Arzhan, Fars	29.66	51.98	[20]
36	Doostiran, Fars	29.78	51.78	[23, 25]
37	Aligoodarz, Lorestan	33.4	49.69	[23]
38	Bardaskan, Razavi Khorasan	35.26	57.97	[23]
39	Khaf, Razavi Khorasan	34.58	60.14	[23]
40	Borzadaran, South Khorasn	32.39	59.22	[23]
41	Manganehi, South Khorasn	32.13	59.56	[25]
42	Golian, South Khorasn	32.8	59.09	[20, 24]
43	Dasht-e Bayaz, South Khorasn	34.03	58.79	[20, 24]

Table 2) Description of environmental variables

BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Table 3) Percentages of contributions of variables included in the best-fitting distribution model for *Ziziphus jujuba*

Variable	Percentage of contribution	Permutation importance
bio6	24.3	0
bio8	23	32.8
bio9	20.5	46.4
slope	16	8.8
bio13	6	4.9
bio15	5.7	0.5
bio4	2.8	6
bio2	1.7	0.5

Findings

Consequently, the most important variables are bio6 (Min Temperature of Coldest Month, 24.3%), bio8 (Mean Temperature of Wettest Quarter, 23%), bio9 (Mean Temperature of Driest Quarter, 20.5%; Table 3). The AUC Mean value of our model was 0.954. In addition, the "area" under the receiver-operating characteristic (ROC) curve has been shown in diagram 1.

Modeling of the potential distribution of *Z. jujuba* reveals the most suitable habitat in central and eastern Iran which also corresponds to South Khorassan province (Figure 1). Besides, results show that the other suitable habitat includes western Afghanistan and southwestern Turkmenistan (Figure 1).

The environmental variables with the most contribution for *Z. jujuba* are bio8 (Mean Temperature of Wettest Quarter), bio6 (Min Temperature of Coldest Month), bio 4 (Temperature Seasonality (standard deviation *100; Diagram 2). These variables have a significant amount of information that is not represented by the other variables.

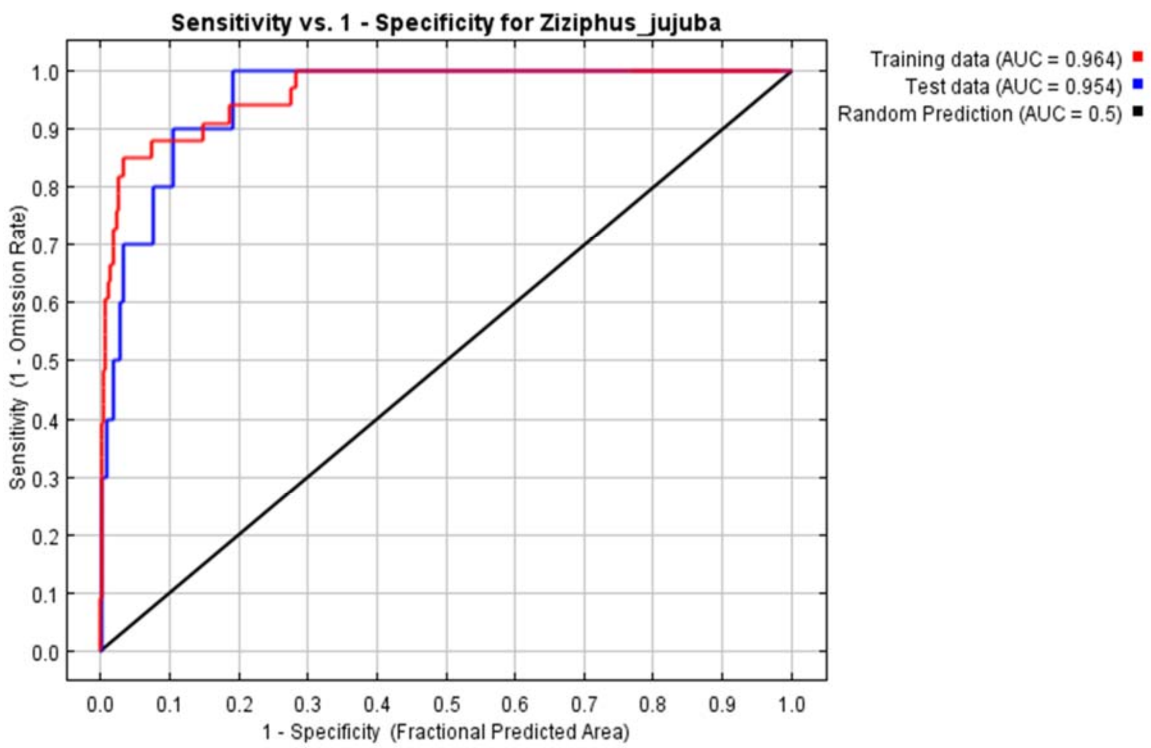

Diagram 1) The results of the area under the receiver operating characteristic (ROC) curve in developing *Ziziphus jujuba*'s habitat suitability model. The red (training) line shows the "fit" of the model to the training data. The blue (testing) line indicates the fit of the model to the testing data and is the real test of the model's predictive power.

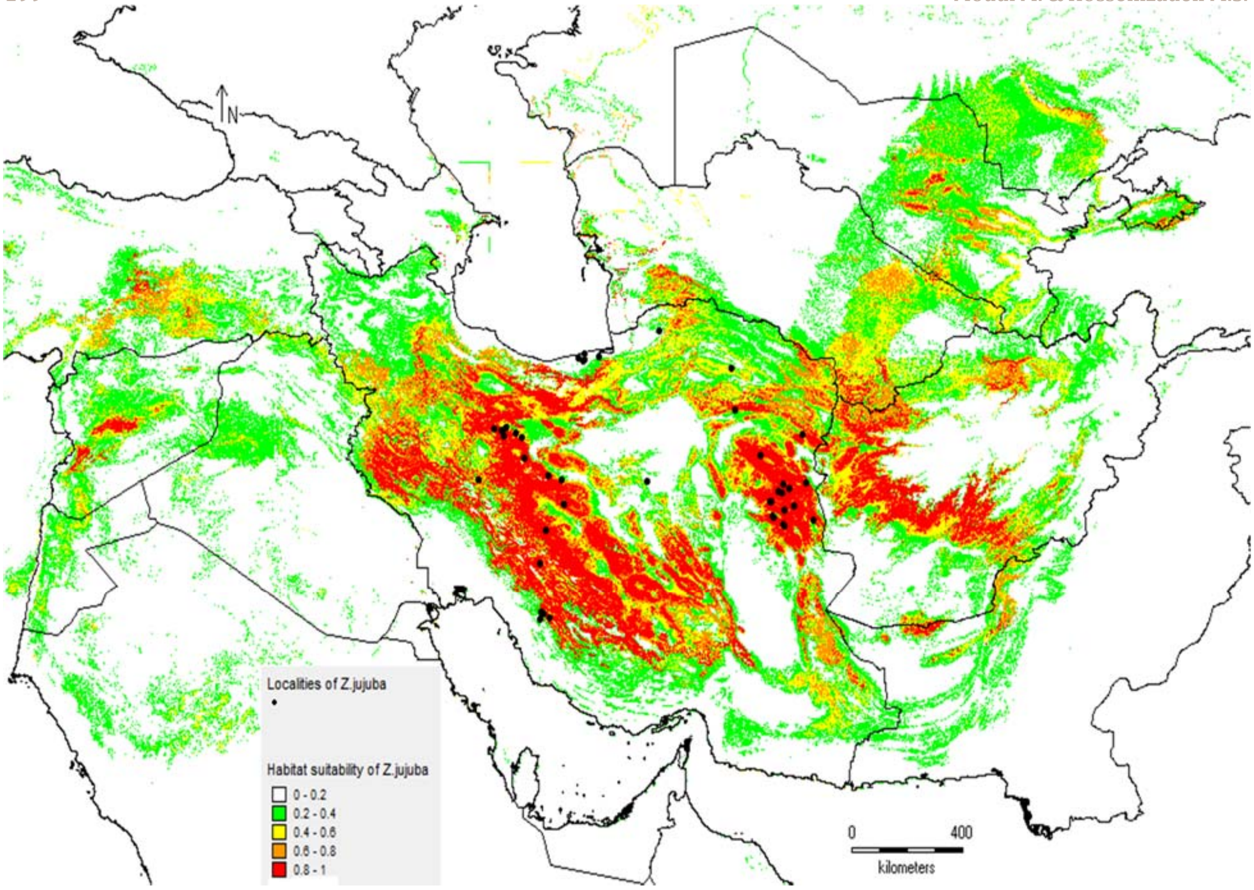

Figure 1) Potential distribution of *Ziziphus jujuba* resulting from the best-fitting MaxEnt model

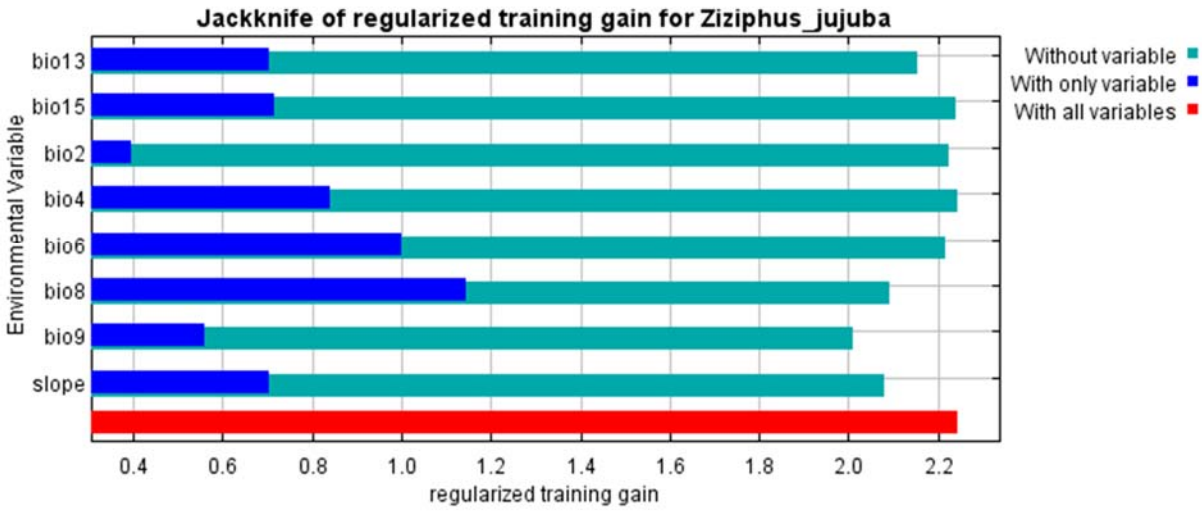

Diagram 2) Results of Jackknife evaluations of importance of the variables used for our *Ziziphus jujuba* MaxEnt model

Discussion

In total, slope, five temperature, and two precipitation variables influenced our final model. Results show that three important variables, bio6, bio8, and bio9, explained 67.8% of all variability in the final model. The calculated ROC showed that the AUC values of training and test data sets were 0.964 and 0.954, respectively. Consequently, the model is classified as satisfactory with the given set of training and test data. Our finding suggests that the most suitable habitat for *Z. jujuba* in central and eastern which partly corresponds to South Khorasan province. According to Mukhtar *et al*., the species is getting popular for its wide adaptation, easy management, rich nutrition, and different usage [32]. Hence, the species has been cultivated in northern Iran such as Golestan and Mazandaran provinces. Our model doesn't show northern Iran as suitable habitat for *Z. jujuba* which probably related to the species has been cultivated and grown wild in some places of this area.

Our results showed that temperature is one of the most important factors in the modeling of *Z. jujuba*. However, Jujube trees raise in arid and semiarid zones that tolerate rainfalls and a wide range of temperatures, requiring hot summers and enduring cold winters [16, 33]. It is tolerant to environmental stresses such as water deficit, chilling, salinity, high temperature, pest, and diseases. *Z. jujuba* occurs in the drier part of Hyrcanian province of Euro-Siberian region, Khorasan-Kopet Dagh floristic province in North Khorasan and the east of Golestan province, with the temperate climate [34]. The studies are completely compatible with the results of this study. Ghazaeian mentioned that the climate effect is very important for the existence of qualitative and quantitative characteristics of jujube [35]. Based on the geographic records of Global Biodiversity Information Facility (GBIF) database, the distribution of *Z. jujuba* has been occurred especially in Asia, between Lebanon, northern India, and southern and central China, and possibly also Europe, North, Central, and South America.

This species as an important tree was planted from about 7700 years ago in China and has been spread from Silk Road to the other places including (India, Iran, Afghanistan, and Central Asia) [23]. It is indigenous to the middle and lower reaches of the Yellow River of China and was first domesticated 7700 years ago. It is cultivated in all the provinces of China except Heilongjiang and Tibet and the total planted area was about 2 million hectares [20, 36]. Abbasi *et al*. showed that the ecotypes were collected in three groups with Isfahani, Mazandaran, and Khorasani origin. Fars ecotypes originated from Esfahan province and Qom ecotypes derived from Esfahani and Mazandaran provinces [23]. In fact, the species probably derived from China and has been penetrated to Iran especially eastern Iran through Silk Road. It is a tree that can be cultivated in the land that does not have suitable water and soil conditions. However, in Iran, cultivating jujube has been seen in most provinces of the country. Jujube tree grows up to 2500 meters in northern Iran such as Gorgan, Gilan, Kashmar and also goes to Baluchestan, Bandar Abbas, Kerman, Shiraz, and around Sistan and Zabol [25]. Mozaffarian indicated that this species can be grown in Esfahan, Khorasan, and Lorestan provinces and cultivated in Gorgan, Gilan, Fars, Bushehr, Kerman, Sistan, Yazd, and Tehran provinces [10].

Taxonomically, there are different ecotypes for *Z. jujuba* Mill which have high variations. The ecotypes were separated according to their geographic origin that might be suggested that the climate effects are very important for the existence of qualitative and quantitative characteristics of jujube [35]. According to Moudi *et al*, there are not genetic distances between different ecotype of *Z. jujuba* but different climate and environment have been changed morphological characters of the species [20]. As mentioned, the species could adapt to different climate especially in arid habitats.

The limitations of this research include just restricted climate factors and the suggestions are continuing study with more closely related species in large scale and studying more environmental factors.

Conclusion

To conclude, the temperature is one of the most important factors in the distribution of Z. jujuba and it is compatible with that Jujube trees rise in arid and semiarid zones which resistance to environmental stresses such as water deficit, chilling, salinity, high temperature, pest, and diseases. However, the most suitable habitat for Z. jujuba in central and eastern which partly corresponds to South Khorasan province. Our findings don't show northern Iran as high suitable habitat for Z. jujuba which probably related to the species has been cultivated and grown wild in some places of this area.

Acknowledgments: The support from the University of Birjand is gratefully acknowledged.

Ethical permissions: In this study, just occurrence coordinates have been used.

Conflicts of Interests: The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Authors' Contributions: Moudi M. (First author), Introduction author/Original researcher or Assistant/Discussion author (60%); Hosseinzadeh M.S. (Second author), Methodologist/Statistical analyst/Discussion author (40%)

Funding/Support: This research received no specific grant from any funding agency in the

public, commercial, or not for profit sector.

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