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Influence of Climatic Factors on Yields of Pistachio, Mango, and Bananas in Iran

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Abstract: The aim of this study was to investigate the impact of climatic variables (minimum temperature, maximum temperature, average precipitation, and precipitation deviation) on the yields of pistachio, banana, and mango in cold, hot–arid, hot–humid, and temperate–humid climates using the Just–Pope function. The Just–Pope function is a relatively new approach in this context. The most effective variables were identified by stepwise regression and the Feiverson algorithm. Data were collected for the period of 1998–2020 and were tested for stationarity. Finally, the coefficients of the Just–Pope function were estimated for the three crops in the four climates. The results showed that the variables affecting pistachio yield were different in each type of climate. Most variables were effective in warm and dry areas, while cropping area, production trend, and lag were effective in cold regions and in hot and humid areas; the maximum deviation and minimum temperature, production lag, cropping area, and production function were significant in hot and dry regions at the 90% level. The Just–Pope function for pistachio, mango, and banana showed that the impact of temperature and average rainfall was region-specific. Based on the results, a 1% increase in rainfall can increase the banana yield up to 0.032 ton/ha. As Iran experiences extensive climatic fluctuations, horticulturists are faced with difficult conditions. Such practices as the use of cultivars that are resistant to temperature and rainfall variations in the regions in order to alleviate the risk of yield variations in orchards are recommended.

Keywords: climate fluctuations; production risk; Just–Pope model; tropical and subtropical crops; Just–Pope function

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1. Introduction

In recent years, human activities have contributed to the increase in the emissions of greenhouse gases, resulting in global warming and climate change. Climate change may entail positive, negative, or neutral effects, depending on the region [1]. Climate is one of the most important factors in determining the agricultural potential of an area and identifying suitable regions for growing certain crops [2–4]. The limitations and boundaries for growing agricultural crops depend on climatic conditions. Thus, climatic parameters are decisive factors for crops and should be given particular attention [5]. According to the Intergovernmental Panel on Climate Change (IPCC), climate change refers to the irreversible change in the average weather conditions of an area relative to the behavior expected to occur in that area over a long time period based on observed or recorded data [6].

Climate change has economic consequences reflected in variations in crop production and supply, yield variations, and impacts on food security. On the other hand, climate parameters that influence farmers' income and profitability show their impact in the long term. Furthermore, the impacts of climate change on domestic crop markets and income distribution among producers and consumers will emerge in various forms and at different times [7].

Climate change influences all economic sectors, particularly the agricultural sector, as the most climate-dependent sector [8–10]. Climate change affects agriculture productivity through rainfall variations, changes in the planting and harvesting dates, temperature rises, and higher evapotranspiration rates [11,12]. It is of crucial importance to evaluate the effects of climate change on crop yields. If climatic factors are not adequately understood, agricultural plans will be destined to fail because agricultural crops will have low productivity [13,14].

Pistachio, banana, and mango are three of the main export crops of Iran that are influenced by climatic conditions, especially temperature and rainfall. In 2016, out of about 2.87 million ha of orchards (including both fertile and non-fertile gardens), about 831,000 ha (i.e., 30.1 percent) grew pistachios, which produced 87.2 million tons, representing 41.7 percent of the total arid fruit production [15]. Additionally, of 2.87 million ha of orchards, 33.4 and 31.4 percent were planted with banana and mango trees, whose fruit products accounted for 67.2 and 19.8 percent of the total tropical fruit production of Iran, respectively [15]. Pistachio is a plant resistant to low or high temperatures that can withstand a wide range of temperatures. It is also resistant to water deficit. In addition to Kerman province, pistachio is cultivated in the provinces of North Khorasan, South Khorasan and Khorasan Razavi, Qazvin, and Qom. The pistachio crop faces a number of climate-related risks, with varying degrees of impact. In fact, climate risk can be influential on pistachio as a vulnerable crop, with the yield reduced by 40%. A climatic risk threatening pistachio is the loss of rainfall. Overall, pistachio is damaged by water deficit. When rainfall is deficient, the moisture decreases in the pistachio production environment, and this impairs its production. This impacts the yield too. Another risk of pistachio production is temperature variations, which may damage the crop during two different periods. Iran is located between the northern latitudes of 25° and 40°. The southern regions of Iran are close to the Tropics of Cancer, where sunlight is almost vertical at noon. This allows the production of many tropical fruits. The tropical fruits of banana and mango are produced in the south of Iran, and the development programs of the country have targeted increasing their cropping area in recent years. The major threats to this sector are the limitations of water resources and sharp drops in groundwater tables due to climate change, reductions in rainfall, drought, and the salinity of a large area of the arable lands of Iran [15]. There are several examples of studies in Iran and other parts of the world on pistachio and tropical fruits (e.g., mango and banana) [16,17]. The agricultural sector is deeply affected by climate variations and changes. To safeguard their livelihood against the impacts of climate change, farmers need to take adaptive actions [18–20]. The agricultural sector of Iran is faced with unstable climatic conditions and unequal spatial and temporal distribution of rainfall, so it is imperative to consider the sustainability of water resources management and methods to counteract drought [21,22]. One of the impacts of climate change is manifested in its damage to the agricultural sector resulting from the variations in precipitation and temperature that impair the production of most horticultural and agricultural crops, with these crops being a main source of food [23]. The present study addresses the question of how the variations in climatic parameters influence the production (average yield and yield risk) of selected tropical and subtropical crops in Iran. Hence, our objective is to explore the effect of the most important climatic factors on the production of and risk to the major selected horticultural crops (pistachio, banana, and mango) of the agricultural sector in Iran. The agricultural and natural resources sector is deeply influenced by natural resources, the weather, and climate [24,25]. It is true that farmers are unable to control climatic conditions, but they can use management practices and change such factors as irrigation, soil, and cultivar to alleviate the harmful impacts of climate change on the growth, development, and yield of crops.

Therefore, the aim of this study is to determine the influence of climatic factors on the yields of pistachio, mango, and bananas in Iran using the Just–Pope stochastic production model. The contribution of the present work lies in the fact that no study in Iran has ever considered the effects of climate variability on the average yield and yield risk of pistachio, banana, and mango crops separately for climatic zones.

2. Methodology

The present study used the stochastic production function of Just and Pope [26] and the fixed effects model to evaluate the impact of climate change on the yield risk to pistachio, banana, and mango in Iran. Panel data on production and yield, and climatic parameters (minimum temperature, maximum temperature, average precipitation, and precipitation deviation) for the period of 1998–2020 were collected from the Ministry of Jihad-e Agriculture and the Iran Meteorological Organization. The model was estimated using the $STATA_{13}$ software package. However, the climatic diversity of Iran in different zones was a source of remarkable differences in the results for the crops in question [27]. As the present study contains hot–arid, hot–humid, temperate–humid, and cold regions, given the limitations in data availability, the climates were selected using Gangi's [28] classification.

Using the Köppen climate classification, Gangi [28] divided Iran's climate into four sub-climates (Table 1 and Figure 1): temperate–humid (southern coasts of the Caspian Sea), cold (western mountains), hot–arid (central plateau), and hot–humid (southern coasts) [29].

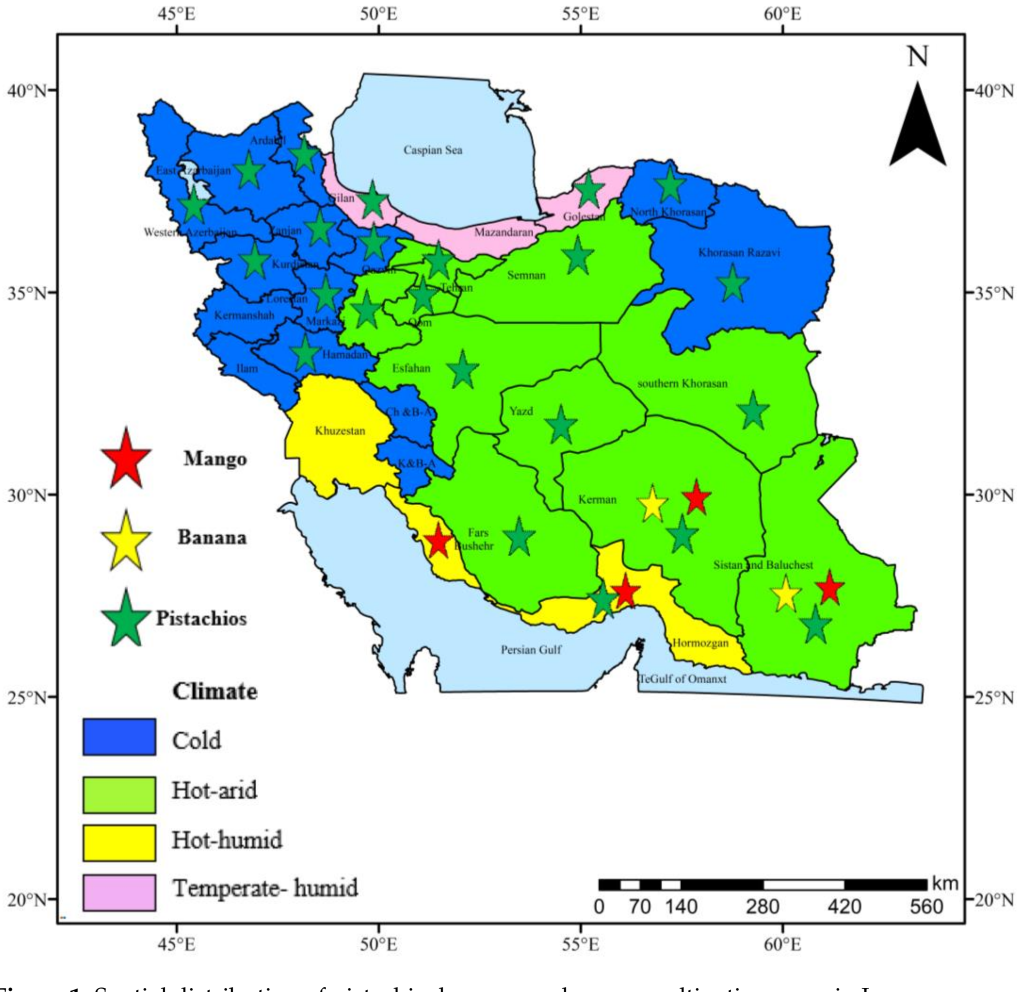

Figure 1. Spatial distribution of pistachio, banana, and mango cultivation areas in Iran.

Table 1. Climatic classification of Iran's provinces (Reference: [28]).

Climate	Provinces Included
Cold	Alborz, Ardabil, East Azerbaijan, West Azerbaijan, Ilam, Tehran, Chaharmahal and Bakhtiari, Razavi Khorasan, North Khorasan, Zanjan, Qazvin, Kurdistan, Kermanshah, Kohgiluyeh and Boyer-Ahmad, Lorestan, Hamadan.
Hot–arid	Fars, Isfahan, Kerman, Markazi, Qom, Semnan, Sistan and Baluchestan, South Khorasan, Yazd.
Hot–humid	Bushehr, Khuzestan, Hormozgan.
Temperate–humid	Golestan, Gilan, Mazandaran.

After testing the data for stationarity, stepwise regression and Feiveson's [30] algorithm were used to select the most effective variables. Then, the Just–Pope stochastic production function was estimated in three stages.

To estimate the Just–Pope empirical model, at first, whether the data can be used as panel data was examined, considering the heterogeneity of climatic regions. To this end, the F Limer test was employed. This test shows if data are panel data and if data can be estimated altogether using the conventional least-squares method. If it is confirmed that the data are panel data, then it is time to make a choice between the fixed-effects model and the stochastic effects model. The stochastic effects model cannot be applied if there are correlations between climatic variables and error terms; otherwise, assumption defects will arise and the estimated coefficients will not be unbiased. However, if their correlation is refuted, the stochastic effects model will be compatible and efficient. Therefore, generally speaking, panel data are the best for estimation. This operation was performed using the Hausman test. The present study directly used the fixed effects model because the model assumes discrepancies induced by regional differences. The general mathematical form of the Just–Pope stochastic production function is as below:

$$y = f(X;b) + \mu = f(X;b) + h(X;a)\varepsilon, \tag{1}$$

where y is the production, X is the vector of independent variables (including production inputs and climatic parameters), $f(X;b)$ is the function of average yield, μ is the heteroscedastic residual with a mean of zero, $h(X;b)$ is the function of yield variance, and ε is the error term of the regression with a mean of 0 and variance of 1. Equation (1) allows the climatic variables to influence the two components of average yield and yield variance through the following equations:

$$E(y_t) = f(x_t, \beta), \tag{2}$$

$$\text{var}(y_t) = h^2(z_t, \alpha), \tag{3}$$

in which y_t is the function, x_t is the independent variables and z_t is the independent variables in the variance function, β is the yield parameter, and α represents the parameters of the variance function. The sensitivity (elasticity) of the yield to the variation in each climatic variable was calculated through the parameters estimated by the average yield function and production risk sensitivity was calculated by the yield variance function [31]. The Just–Pope function is composed of two parts, i.e., yield and yield variance, which are accounted for by the variation in the climatic variables. Just and Pope suggested a three-stage process of feasible generalized least squares (FGLS) to estimate their model. In stage one, the variable yield was estimated over the function $f(X,\beta)$ and the results of least squares were then calculated as $\hat{\mu} = y - f(x)$, in which $\hat{\mu}$ is a consistent estimate of μ with heteroscedasticity and mean of 0. In stage two, the estimated $\hat{\mu}$ was estimated over its asymptotic expectation $h(X;\alpha)$. In stage three, the error predicted in stage two was used as the weight of the first equation (average yield function), and the yield function was reassessed. Under these conditions, the estimated β was consistent and efficient for stochastic production functions. Indeed, this method allowed for modifying the heteroscedasticity of stage one [32]. In these stages, the presence of the trend variable was tested in the model. In summary, the set of estimated parameters β and α provided us with data regarding the effect of climatic variables on the average crop yield and its variance. In other words, β was estimated by regressing the average yield in stage three and the impact of climatic parameters on the average yield estimated. In this research, the significance level is 90%.

It should be noted that, in this study, the trial-and-error method, or, in other words, the combined method was used for calibration. In the calibration stage, the most sensitive parameters were identified. Then, external validation was performed; if this validity was confirmed, after the sensitivity analysis, validation was performed.

3. Results and Discussion

First, we used the augmented Dickey–Fuller (ADF) unit root test to check the stationarity of the variables. The ADF test was used to avoid the occurrence of false regression due to the presence of unit roots in the variables. This false regression made the results unreliable. Table 2 shows the results of ADF for the stationarity or non-stationarity of the model variables. The Fischer-ADF stationarity test is usually used for panel data when the cross-sections are few and limited. The reason for the application of ADF was that the cross-sections in this study were few and limited (268 cross-sections).

Table 2. Fischer-ADF test results for the variables included in the Just–Pope model.

Climate	Variables	Lag Length	ADF Test
Hot–arid climate	Pistachio acreage	1	83.11 (0.00)
	Mango acreage	1	32.62 (0.00)
	Pistachio production level	0	42.52 (0.00)
	Mango production level	1	35.77 (0.00)
	Pistachio minimum temperature deviation	1	71.06 (0.00)
	Pistachio maximum temperature	0	61.14 (0.00)
	Mango rainfall deviation	0	13.93 (0.00)
	Mango minimum temperature deviation	1	9.22 (0.00)
	Mango maximum temperature deviation	1	21.31 (0.00)
Cold climate	Pistachio acreage	1	85.82 (0.00)
	Pistachio production level	1	106.49 (0.00)
	Pistachio rainfall deviation	0	51.25 (0.00)
	Pistachio minimum temperature	0	38.58 (0.01)
Hot–humid climate	Banana acreage	1	27.03 (0.00)
	Banana production level	1	30.21 (0.00)
	Banana average rainfall	1	32.18 (0.00)
	Banana maximum temperature	0	22.09 (0.00)
Temperate–humid climate	Pistachio acreage	1	21.55 (0.00)
	Pistachio production level	1	32.69 (0.00)
	Pistachio rainfall deviation	0	17.97 (0.00)
	Pistachio minimum temperature	2	25.39 (0.00)

Table 2 summarizes the results of the stationarity tests for four zones, including hot–arid, hot–humid, temperate–humid, and cold, for pistachio, mango, and banana. Most variables became stationary after one-time differentiation. To ease concern about the wrong results for the relationships of the variables, the logarithm transformation and/or the variables themselves were used in estimating the four-climate model. Table 3 presents descriptive statistics for the variables included in the Just–Pope function for the four climates. These data cover the time period from 1998 to 2020.

As mentioned in the methodology section, we employed stepwise regression and Feiveson (2012)'s algorithm to select the most effective climatic variables for the model. The results of Feiverson (2012)'s algorithm are given in Table 4.

Table 3. Descriptive statistics of the variables in the study regions (1998–2020).

Climate	Product	Mean	Maximum	Minimum	ADF Test
Hot–arid climate	Pistachio acreage (ha)	34.55	303.27	66	72,365.48
	Mango acreage (ha)	1219	2810	143	876.02
	Pistachio production level (Ton)	19,569	265,540	0	40,158.46
	Mango production level (Ton)	7886	22,489	21	6478.41
	Pistachio min. temp. deviation (°C)	8	29	5	2.28
	Pistachio max. temp. (°C)	25	29	11	2.16
	Mango rainfall deviation (°C)	15	59	3	10.13
	Mango min. temp. deviation (°C)	7	22	5	2.13
	Mango max. temp. deviation (°C)	8	32	4	3.64
Cold climate	Pistachio acreage (ha)	5311	73,077	1	13,653.52
	Pistachio production level (Ton)	3509	50,139	1	9551.38
	Pistachio rainfall deviation (mm)	26	69	8	10.37
	Pistachio min. temp. (°C)	7	84	2	6.01
Hot–humid climate	Banana acreage (ha)	983	5678	1	1748.51
	Banana production level (Ton)	21,789	128,900	0	41,302.26
	Banana average rainfall (mm)	10	37	1	7.22
	Banana max. temp. (°C)	29	33	24	2.65
Temperate–humid climate	Pistachio acreage (ha)	167	1266	2	248.90
	Pistachio production level (Ton)	122	1415	1	235.21
	Pistachio rainfall deviation (mm)	47	126	4	34.18
	Pistachio min. temp. (°C)	16	33	19	4.96

Table 4. Selection of the most effective predicted variables for the Just–Pope function.

Climate Type	Products	Variables
Hot–arid climate	Pistachio	Acreage, minimum temperature deviation, maximum temperature, trend, production lag
	Mango	Acreage, rainfall deviation, maximum temperature deviation, minimum temperature deviation, production lag
Cold climate	Pistachio	Acreage, rainfall deviation, minimum temperature, trend, production lag
Hot–humid climate	Banana	Acreage, average rainfall, maximum temperature, trend, production lag
Temperate–humid climate	Pistachio	Acreage, rainfall deviation, minimum temperature, trend, production lag

Here, the results of estimating the Just–Pope empirical model for the four different studied climates are presented. The results of the three-stage estimation of the Just–Pope function for the years 1998–2020 can be seen in Tables 5–7. The variables are logarithmic. The dependent variable in the average function was the log of the average annual production of the crop. The dependent variable in the variance function was derived from the log of error square calculated in stage one.

Based on Table 7, in the yield function of pistachio in hot–arid regions, the variables of acreage, trend, and production lag are significant at the 90% level, and the variables of minimum temperature deviation and maximum temperature are not significant. The estimated coefficients of the Just–Pope function average component show that the pistachio production level increased in hot–arid regions as the acreage, maximum temperature, and trend increased. The coefficient of the temporal trend indicated a 1% annual positive effect. In addition, the variables of production lag and minimum temperature deviation had adverse impacts, so a 1% increase in production lag resulted in 1.09% lower production and a 1% increase in minimum temperature deviation resulted in 0.05% lower production. As expected, the increase in acreage, maximum temperature, and trend were recognized as increasing risk, and the decrease in minimum temperature deviation and production lag were recognized as decreasing the risk to pistachio production.

Table 5. Estimation of the Just–Pope function coefficients for pistachio in the hot–arid zone.

Function	Variable	Coefficients	SD	z-Statistic	Prob.
Mean function	Acreage	0.448	0.081	5.48	0.00
	Min. temp. deviation	−0.058	0.136	−0.43	0.66
	Max. temp.	0.906	0.890	1.02	0.30
	Trend	0.014	0.002	5.58	0.00
	Production lag	−1.09	0.209	−5.25	0.00
No. of observations = 189; Prob > chi2 = 0.00; Wald chi2 (14) = 2461.59					
Variance function	Acreage	0.352	0.135	2.61	0.00
	Min. temp. deviation	−0.156	0.282	−0.56	0.57
	Max. temp.	1.717	0.924	0.89	0.37
	Trend	0.019	0.004	4.38	0.00
	Production lag	−1.030	0.317	−3.25	0.00
Wald chi2 (14) = 1582.07; Prob > chi2 = 0.00; F(1,9) = 21.456; Prob > F = 0.00					

Table 6. Estimation of the Just–Pope function coefficients for pistachio in the cold zone.

Function	Variable	Coefficients	SD	z-Statistic	Prob.
Mean function	Acreage	1.052	0.040	25.80	0.00
	Min. temp. deviation	0.084	0.079	1.06	0.29
	Max. temp.	−0.359	0.222	−1.61	0.10
	Trend	0.004	0.002	1.70	0.09
	Production lag	0.233	0.043	5.39	0.00
No. of observations = 208; Prob > chi2 = 0.00; Wald chi2 (15) = 760.18					
Variance function	Acreage	1.048	0.041	25.39	0.00
	Min. temp. deviation	0.082	0.080	0.08	0.30
	Max. temp.	−0.347	0.216	0.21	0.10
	Trend	0.004	0.002	0.00	0.04
	Production lag	0.271	0.045	0.04	0.00
Wald chi2 (15) = 741.47; Prob > chi2 = 0.00; F(1,10) = 1792.82; Prob > F = 0.00					

Table 7. Estimation of the Just–Pope function coefficients for pistachio in the temperate–humid zone.

Function	Variable	Coefficients	SD	z-Statistic	Prob.
Mean function	Acreage	0.326	0.22	1.48	0.14
	Min. temp. deviation	−0.263	0.28	−0.91	0.36
	Max. temp.	−4.925	2.14	−2.29	0.02
	Trend	0.030	0.01	2.38	0.01
	Production lag	1.595	0.93	1.70	0.08
No. of observations = 56; Prob > chi2 = 0.00; Wald chi2 (7) = 43.99					
Variance function	Acreage	0.749	0.242	3.09	0.00
	Min. temp. deviation	−0.889	0.607	−1.46	0.14
	Max. temp.	−13.015	2.567	−5.07	0.00
	Trend	0.075	0.020	3.66	0.00
	Production lag	1.583	1.508	1.05	0.29
Wald chi2 (7) = 73.26; Prob > chi2 = 0.00; F(1,2) = 4.823; Prob > F = 0.00					

In the average pistachio function in cold regions, the variables of acreage, trend, and production lag were significant at the 90% level, and rainfall deviation and minimum temperature were insignificant. In cold regions, the production level of the average function was adversely influenced by the minimum temperature and trend. In fact, a 1% higher minimum temperature resulted in 0.35% lower pistachio production. The increase in the annual minimum temperature in this region was involved in the higher variance in the pistachio yield. The coefficient of rainfall deviation derived from the estimation of the average pistachio component in the Just–Pope function was 0.084 in these regions, implying positive long-term effects of rainfall on production. In addition to the variables of acreage and rainfall deviation, the variables of temporal trend and production lag were found to have a slight significant and positive influence on the yield and production risk of pistachio in cold regions. In other words, the effect of time on the pistachio yield was, on average, 0.004% in these regions.

The results of estimating the Just–Pope function for pistachio in temperate–humid regions were also as expected. The increase in the minimum temperature and rainfall deviation influenced the average production level of pistachio significantly at the 90% level. In other words, a 1% higher minimum temperature reduced the pistachio yield in temperate–humid regions by 4.93%, and a 1% higher rainfall deviation reduced it by 0.263%. A look at the stochastic component of the Just–Pope function for this crop showed that, in these regions, except for rainfall deviation and minimum temperature, which were the decreasing risk factors, the other parameters, including acreage, trend, and production lag, were among the increasing risk factors, implying that their increase would be followed by an increase in the pistachio yield variance.

With respect to mango crop in hot–arid regions (Table 8), the negative impacts of climate change were evident on both average production and its variance.

Table 8. Estimation of the Just–Pope function coefficients for mango in the hot–arid zone.

Function	Variable	Coefficients	SD	z-Statistic	Prob.
Mean function	Acreage	0.217	0.089	2.43	0.01
	Min. temp. deviation	−0.034	0.503	−0.69	0.49
	Max. temp.	−0.1397	0.649	−2.15	0.03
	Trend	−1.009	0.454	−2.22	0.02
	Production lag	−0.224	0.059	−3.74	0.00
No. of observations = 56; Prob > chi2 = 0.00; Wald chi2 (7) = 3.28					
Variance function	Acreage	−4.584	1.48	−3.10	0.00
	Min. temp. deviation	0.984	0.90	1.09	0.27
	Max. temp.	3.713	11.40	2.69	0.00
	Trend	25.685	7.98	3.22	0.00
	Production lag	0.838	1.01	0.82	0.41
Wald chi2 (7) = 36.37; Prob > chi2 = 0.00; F(1,2) = 22.34; Prob > F = 0.04					

A 1% increase in annual rainfall deviation showed a 0.034% loss of production. Additionally, as the deviations in minimum and maximum temperatures annually increased by 1%, the mango production level decreased by 1.397 and 1.000 percent, respectively. These climatic parameters influenced mango production adversely. They were recognized as increasing risk factors. The variable of acreage was a decreasing risk factor; that is, the yield variance decreased as the acreage increased.

The results of the estimation of the Just–Pope function of pistachio in warm and dry, cold, and hot–arid regions (Tables 5–7) indicated that, when rainfall variables changed, acreage and maximum temperature had a positive effect on production, but when the minimum temperature deviation changed, the minimum temperature had a negative effect on production. These results can be drawn from the findings of Khoshhal Dastjerdi and Shahsavari [16], Yarahmadi et al. [18], Darijani et al. [33], and Benmoussa et al. [34].

The effects of variations in climatic parameters were not significant on average banana production in hot–humid regions (Table 9). Looking at the coefficient of average banana production function in hot–humid regions, one can see that a 1% increase in rainfall could improve production by 0.032%, and despite the fact that the maximum temperature did not affect yield, production lags can influence production desirably. The impacts of average rainfall and maximum temperature were positive on banana production risk in these regions, so a 1% increase in these two parameters increased the production variance by 0.3 and 30.27%, respectively. Furthermore, the variable of trend in the Just–Pope function of banana in these regions implied that the technological and institutional impacts improved the production of this crop by 0.056% every year.

Table 9. Estimation of the Just–Pope function coefficients for banana in the hot–humid zone.

Function	Variable	Coefficients	SD	z-Statistic	Prob.
Mean function	Acreage	0.159	0.14	1.13	0.25
	Min. temp. deviation	0.032	0.10	0.29	0.76
	Max. temp.	0.714	2.04	0.35	0.72
	Trend	0.003	0.00	0.53	0.59
	Production lag	0.804	0.85	0.95	0.34
No. of observations = 75; Prob > chi2 = 0.91; Wald chi2 (8) = 3.28					
Variance function	Acreage	2.098	0.33	6.34	0.00
	Min. temp. deviation	0.300	0.39	0.76	0.44
	Max. temp.	30.27	6.08	4.97	0.00
	Trend	0.056	0.02	2.00	0.04
	Production lag	5.554	1.78	3.21	0.00
Wald chi2 (5) = 78.26; Prob > chi2 = 0.00; F(1,3) = 1792.82; Prob > F = 0.06					

According to the results of the Just–Pope function for mango in the hot–arid zone (Table 8), with the change in precipitation deviation, the minimum and maximum deviations in the temperature had a negative effect and acreage had a positive effect on production. Additionally, for banana crop (Table 9), the variables of acreage, maximum temperature, and average rainfall were all positive factors in increasing the production level of banana in hot and humid areas. These results are consistent with the findings of Shafaghati and Senobar [35], Nori et al. [19], Van den Bergh et al. [20], and Machovina and Feeley [22].

Climate diversity and its short- and long-term variations play a key role in dictating production and its sustainability. This is why researchers have focused on the effect of future climate changes on the agricultural sector and its products [36,37]. Deschenes et al. [38], Hayes et al. [39], Peck et al. [40], and Massetti and Mendelsohn [41] focused on the relationship among climate change, drought, and agricultural production, in which the economic impacts of climate change on agriculture were explored using various approaches, e.g., mathematical programming, production models, climatic models, and the Ricardian approach. Reilly et al. [42], Calzadilla et al. [43], and Leimbach et al. [44] used macroeconomics, commerce, and integrated assessment models to explain the role of agriculture in the economy as influenced by climate change. Medellín-Azuara et al. [45], Thornton et al. [46], Aishabokhae et al. [47], Gollin [48], Fleischer and Kurkulasuriya [49], Ochieng et al. [50], and Bai et al. [51] explored how to adapt agriculture to climate change using mathematical programming models. Chen et al. [52], Isik and Devadoss [53], McCarl et al. [54], Barnwal and Kotani [55], Holst et al. [56], Sarker et al. [57], and Arumugam et al. [58] assessed the impacts of climate change on crops, such as corn, cotton, rice, potato, barley, and so on, using the Just–Pope function. Shafaghati and Senobar [35] studied the production of banana as a major greenhouse product in the north of Iran. Banana production is of economic significance in Iran owing to its high yield and consumption potential. The production of this crop has been confined to the provinces of Sistan and Baluchistan and Hormozgan, as well as some parts of Jiroft. However, given the favorable soil conditions and the Mediterranean climate of the northern regions and other parts of Iran, it is possible to grow banana in plastic greenhouses, where environmental parameters can be controlled. Khoshhal Dastjerdi and Shahsavari [16] studied environmental conditions and calculated the thermal requirements of pistachio in Borkhar Plain in 2002–2003. During this period, rainfall and radiation were identified as two climatic components limiting the biological activity of pistachio, whereas atmospheric relative humidity and soil type imposed no limitations. The forecast of the probable dates of initiation, duration, and development of each phenological phase and the probability of encountering spring and early autumn chilling in this region were among the other findings of this research. Nori et al. [19] explored the impact of rainfall variations on crop production (date, citrus, mango, banana, local olive, tree melon, wheat, barley, rice, onion, forage corn, and alfalfa) in the southeast of Iran. They reported a significant relationship of crop production with droughts and wet years in the regions. Van den Bergh et al. [20] studied climate change in the subtropics and the impacts of projected averages and variability on banana productivity. The analysis showed that, in terms of environmental conditions, certain sites were widely represented globally, offering options for technology transfer between sites. Other sites had few similar sites, which meant that sites would need to be carefully selected for approaches to technological development and transfer. The study leveraged site-specific information with widely available tools to understand the potential effects of climate change in the subtropics. However, in order to fully understand the impacts of climate change on banana, the modeling tools used need to be fully suited for semi-perennial crops to capture the effects of seasonal temperature and rainfall variability on crop cycle length and potential yield. Using the SDM model, Machovina and Feeley [22] explored climate change-driven shifts in the extent and location of areas suitable for export banana production. The extent of areas suitable for organic banana cultivation was predicted to nearly double due, primarily, to climatic drying. Several countries (e.g., Colombia and Honduras) were predicted to experience large net decreases in the extent of areas suitable for banana cultivation. Some countries (e.g., Mexico) were predicted to experience large net increases in the extent of suitable areas. Pish Bahar et al. [17] studied the effect of rainfall decline on the production of apple, potato, pistachio, and date as export crops, and wheat, soybean, and tea as import crops using the Monte Carlo simulation approach. Their results showed that, as rainfall decreased, wheat supply decreased more than that of other crops, and apple supply decreased less than that of other crops. In terms of trade, the export rate and value of apple were most responsive to and the import value of soybean was the least responsive to rainfall decline. Additionally, the trade balance of crops was negative, and the negative growth intensified as rainfall declined further. Thus, it is recommended to increase production in this sector and to make savings in water consumption. In a study on the climatic zonation of the pistachio growth region in Eastern Azerbaijan province, Yarahmadi et al. [18] found that it was quite feasible to replace the present orchards in the region, which have high water requirement, with pistachio orchard. Benmoussa et al. [34] studied the threats of climate change to Central Tunisian nut orchards. Their findings indicated severe chill losses for all future scenarios. For all species, the current chill period was no longer expected to be sufficient for meeting chilling requirements in the future. Chill needs may still be fulfilled later in the year, especially for low-chill almonds, but this would result in delayed phenology, with possible adverse effects on productivity. Darijani et al. [33] evaluated the resilience of pistachio agroecosystems in Rafsanjan Plain in Iran. Their results showed that the study areas had a problematic status regarding the indicators of membership in grassroots organizations, innate abilities, water sources, production stability, and insurance. They had a critical or moderate status concerning the indicators of the use of organic fertilizers, use of pesticides, soil fertility index, water-use efficiency (kg/m^3), trust in the government, access to advisor services (extension), on-the-job training, and diversity of marketing. They had positive status for the indicators of productivity, diversity of cultivars, diversity of on-farm practices, and exchange of information. Pathak et al. [59] explored climate change trends and impacts on California agriculture. Their detailed review provided sufficient evidence that the climate in California has changed significantly and is expected to continue changing in the future, and justified the urgency and importance of enhancing the adaptive capacity of agriculture and reducing vulnerability to climate change.

Despite their extensive use, these approaches have certain drawbacks. One assertion of our model as compared with similar models is that climate change influences the yield variance, in addition to the yield itself. As crop yield variance may cause yield variations, price instability, and market risk, both effects should be simultaneously estimated when the impact of climate change is addressed. Therefore, crop yield variance is also considered when Just and Pope's function is applied. On the other hand, as a plethora of climatic variables are available, instead of arbitrary selection, as was performed in Just and Pope's empirical model [26], we employed the results of stepwise regression and Feiveson [30] algorithm to choose the variables. Additionally, given the remarkable heterogeneity across Iran, we estimated the empirical function for each climatic zone based on Gangi's [28] classification separately.

4. Conclusions

The present study focused on the effects of climatic parameters on the crop yield and risk of selected species (i.e., pistachio, mango, and banana). The results of estimating the Just–Pope function for pistachio crop in hot–arid, cold, and temperate–humid climates revealed that the production level increased with the decrease in temperature deviation and the increase in maximum temperature in hot–arid regions, with the increase in rainfall deviation and the decrease in minimum temperature in cold regions, and with the decrease in rainfall deviation and minimum temperature in temperate–humid regions. Additionally, the impact of climate change on mango and banana crops in hot–arid and hot–humid climates indicates that the crop yield increased with the decrease in rainfall deviation, minimum temperature deviation, and maximum temperature deviation for banana crop in hot–arid regions and with the increase in average rainfall and maximum temperature for mango crop in hot–humid regions. On the other hand, given the effects of the variable of trend, which reflected that the technical changes in production technology are positive and significant, it is necessary to adopt such practices as the use of resistant and improved cultivars, changing agricultural management methods towards yield enhancement, the promotion of no-tillage farming, and the development of irrigation along with the introduction of new cultivars of banana, mango, and pistachio.

The results of the estimations show that the impact of temperature and rainfall is region-specific, so regions with various climates are influenced by these parameters differently. The low and slight variability in the yield and production risk of the studied crops can be explained by the fact that the production activities mainly occur in under-optimal climatic conditions. This income loss, in turn, will discourage farmers, resulting in a reduction in agricultural production. The ultimate consequence may be the indirect impacts on commerce, development, and food security.

Given the fact that agriculture is a main economic sector and climatic conditions play a crucial role in agricultural production, it is of high importance to understand the climatic potential in order to recognize regions appropriate for different agricultural crops and to ensure agricultural diversity. To use highly efficient resources, we need to know the weather conditions and climatic potential of the regions.

Overall, the results of the present study demonstrate that the variations in climatic variables, such as average temperature and annual rainfall, influence the yield of pistachio, mango, and banana, in that sudden changes in each climatic parameter and their fluctuations throughout the growth period of these crops can reduce yield. The second priority should be given to increasing their acreage. On the other hand, considering the impact of climate change (temperature rise and rainfall decline) in recent years, it is recommended to adopt policies to improve the yield per unit area of the studied crops, as they are the main export horticultural crops of Iran.

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