University of Tehran Press

DESERT

Home page: https://jdesert.ut.ac.ir/

Online ISSN: 2345-475X

Evaluating Climatic Suitability for Various Almond Cultivars under Rainfed Conditions in semiarid regions of Iran

Zohreh Mosleh Ghahfarokhi[1*], Asghar Mousavi[2]

[1] Department of Soil Science, College of Agriculture, Shahrekord University, Shahrekord, Chaharmahal and Bakhtiari, Iran. E-mail: z.mosleh@areeo.ac.ir

[2] Department of Horticulture Crops Research, Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension organization (AREEO), Shahrekord, Chaharmahal and Bakhtiari, Iran.

Article Info.

Article type:
Research Article

Article history:
Received: 29 Oct. 2024
Received in revised from: 19 Dec. 2024
Accepted: 23 Dec. 2024
Published online: 27 Dec. 2024

Keywords:
Climatic parameters,
Suitability index,
Almond,
Cultivar,
Flowering time,
Rainfed.

ABSTRACT

This study evaluated the climatic suitability of several almond cultivars that flower at different times: Sefied, which flowers early, Mamaei and Rabie, which flowers in the middle, and Shahroud 7 and 12, which flowers late. The phenological stages of almond trees were first identified using prior research and discussions with provincial horticultural experts. After gathering long-term climate data, the climate requirements of almond plants were compared with the regional climate factors. Subsequently, the climatic suitability classes were identified, and a corresponding map was created. The evaluation of climatic suitability for early-flowering cultivars revealed that the province's climate presents severe to very severe limitations for growing and cultivating this crop, with a large percentage of the province (roughly 53.3%) experiencing very severe limitations, meaning that the climate is unsuitable for these cultivars. The climate of the province for mid-flowering almond cultivars varies with regions categorized into severe limitations, very severe limitations (correctable), and non-correctable very severe limitations. Nonetheless, the majority of the province's counties are classified as S3 suitability class (severe limitation) for cultivating and developing mid-flowering cultivars. For late-flowering cultivars, the climate of the province across all counties falls within the S3 suitability class. Therefore, the climatic suitability of a region varies not only for each plant but also for different cultivars of the same plant. Additionally, the most limiting climatic parameter is the average minimum temperature during the flowering stage. In order to maximize production and lessen climate-related constraints, the study emphasizes how crucial it is to choose suitable almond cultivars based on blooming timings and local climate conditions, especially the average minimum temperature during the flowering stage.

Cite this article: Mosleh Ghahfarokhi, Z., Mousavi, A. (2024). Evaluating Climatic Suitability for Various Almond Cultivars under Rainfed Conditions in semiarid regions of Iran. DESERT, 29 (2), DOI: 10.22059/jdesert.2024.100470

DOI: 10.22059/jdesert.2024.100470

Publisher: University of Tehran Press

1. Introduction

The yield of agricultural products is greatly influenced by a region's climate, so determining a region's climatic potential is an important part of planning and making decisions about the growth of orchards and which crops are best suited for cultivation there. Before doing additional research, such as a soil analysis, assessing a region's climatic potential for planting and growing orchards can help discover variables that limit productivity and help decision-makers choose the right crop. Even while humans cannot totally control the climate, they can reduce the suffering caused by unsuitable food production conditions by researching certain climate factors and how they vary in a particular location. Because orchard crops need more time and money to produce a harvest than the field crops, this problem is especially significant for orchard crops. If the incorrect path is chosen, it may result in irreversible damage and hinder the development of orchards.

According to Javadi *et al.* (2014), one of the most important prerequisites for agricultural productivity in developed nations is knowledge of weather conditions and annual variations in meteorological parameters, as well as their departures from normal values. Climatic characteristics are important and calculable not only for different time periods but also for various stages of a plant's phenology (Seyed Mohammadi *et al*., 2023). Agricultural climatology refers to the set of climatic conditions that enable the economic cultivation of plants from a climatic perspective (Ahmadi and Fallah, 2015). Thus, one of the ways to achieve sustainable development and food security is through zoning production areas based on agricultural climatology (Seyed Mohammadi *et al*., 2023). In addition to placing restrictions on agricultural cultivation, climate has a significant impact on crop production stability. Furthermore, in order to select and invest in the best cultivars suitable for the environment of each location, it is imperative to make decisions on the primary climatic parameters (Shojaei *et al*., 2019).

Recent studies underscore the significance of integrating long-term climatic data into crop selection processes. For example, studies by Daccache *et al*. (2014) and Yan *et al*. (2020) highlight the potential of water-efficient practices and cultivar adaptation to mitigate risks associated with climatic variability.

It is also important to keep in mind that while assessing cultivars and climatic conditions is the first step toward attaining sustainable development, subsequent stages require consideration of other factors including soil characteristics and topography. Niu *et al*. (2018) declared that climate and soil quality are the two most important factors influencing productivity. MaghamiMoghimi *et al*. (2013) state that if a region's climate—temperature, precipitation, etc.—is unsuitable, assessing other features—soil and topography—becomes unjustifiable. For rainfed agriculture, therefore, the assessment of climatic suitability takes precedence over other features.

Bagheri Bodaghabadi *et al*. (2020) evaluated the land suitability for horticultural crops such as apricots, peaches, apples and almonds. Results showed that 86.87% of the whole land are suitable for apricots. For almonds, the land suitability classes were S2, S3 and N classes, in 21.90%, 65.57% and 90% of the area, respectively. The most important limitations were the soil depth, gravel, slope, and climatic constraints.

Seyed Mohammadi *et al*. (2023) stated that for most orchard crops, average temperature is the most important and, in a sense, the most limiting climatic factor, though its importance varies across different phenological stages. Yarahmadi *et al*. (2023) also mentioned that insufficient attention to the limitation of high relative humidity during different stages of pollination and fruit growth has hindered the development of pistachio orchards in Ardabil

Province. Kumar *et al*. (2021) demonstrated that soil suitability maps of fruit crops are helpful in developing strategies for proper soil and water conservation measures, and in adoption of best management practices.The integration of climatic indices, as shown by Hansen (2002), further improves the precision of assessing land suitability for perennial crops like almonds.The almond tree (*Prunus dulcis* Mill.), belonging to the *Rosaceae* family, is native to regions ranging from western Asia to the Mediterranean basin. Fars, Chaharmahal and Bakhtiari, East Azerbaijan, and North Khorasan are the nation's top producing provinces for almonds. Almonds grow best at temperatures between 14°C and 27°C, and they need to be chilled for 200–700 hours at temperatures lower than 7°C (ZeynaldiniMimand *et al*., 2019). Almond blossoms are highly sensitive to late spring frosts. Early warnings and creating conditions to adapt agricultural activities to climatic variables help reduce the level and extent of risks. Climate feasibility studies for orchard development are crucial because of the scarcity of water resources, the risks posed by climate change, and the growth of orchards on sloped terrain. Because of its distinct topography and geography, Chaharmahal and Bakhtiari Province has a wide range of climates. Almonds are a crop with significant economic value, thus it's critical to cultivate them as best as possible given the local climate. Therefore, to maximize the climatic potential of the area, knowing its constraints and coming up with workable solutions should make it easier to grow and develop rainfed orchards in this province. The purpose of this study was to determine whether the province's climate is suitable for growing almond types with varying flowering dates in rainfed environments.

2. Materials and Methods

2.1. Study area

Chaharmahal and Bakhtiari Province, covering an area of 1,633,677 hectares, is located between coordinates 49°30' to 51°26' E longitude and 31°9' to 32°38' N latitude. According to the Köppen climate classification, this province has two climatic zones: humid steppe and humid. Based on the Emberger method, it features three climates: cold semi-arid, semi-humid, and high-altitude regions. According to the De Martonne classification, the province encompasses four climates: semi-arid, semi-humid, Mediterranean, and very humid.

2.2. Climatic suitability

Almond phenology, mainly flowering and fruit set stages, are key process for yield as the occurrence of hazardous weather conditions during those critical stages has a major impact (Lorite *et al*., 2020). Given that climatic feasibility assessments and the alignment of climatic parameters with the specific needs of each plant depend on various growth stages and phenological periods, the phenological stages of almond trees for three different varieties—early-flowering (Sefied), mid-flowering (Mamaei and Rabie), and late-flowering (Shahroud 7 and 12)—were determined based on prior research and consultations with provincial horticulture experts. Subsequently, a database was created using meteorological, climatological, and agricultural statistics from synoptic stations in the province for the 20-year period ending in 2021 (Table 1).

The almond crop has clear climatic requirements that must be considered for the cultivar and location selection (Pope *et al*., 2014). The climatic requirements of the almond (Table 2) were compared with the climatic factors of the area, accounting for the timing of each phenological stage, to determine the climatic index. The parametric method was used to determine the scores for each feature. In this method, each feature under the categories of precipitation, temperature, relative humidity, and sun radiation is given a numerical rating between 0 and 100 using tables that explain the climatic needs for each crop. For the sake of further computations, the feature with the lowest score among those available in each climatic category is deemed representative of that group (ZeynaldiniMimand *et al*., 2019).

Table 1. Climatic data of synoptic stations in the province for the 20-year period ending in 2021

Climate station	Precipitation (mm)	Mean temperature (°C)	Minimum temperature (°C)	Relative humidity (%)
Ardal	536.4	15.8	9.1	38
Boldaji	402.4	10.6	2.3	45
Broujen	259.3	11.5	3.7	36
Dezak	471.8	11.7	3.0	41
Emamghaeis	621.3	11.4	4.2	45
Farokhshahr	245.8	12.9	4.0	41
Farsan	506.4	12.4	4.8	42
Kohrang	1328	10.0	3.1	43
Lordegan	563.8	15.9	7.5	51
Malkhalifeh	594.4	15.4	6.9	41
Saman	338.1	13.5	6.6	36
Shahrekord	320.9	11.3	1.8	42

Table 2. Climate requirements of Almond

Climatic characteristics	Class and rating scale of limitation					
	S1	S2	S3		N1	N2
	100	95	85	60	40	25
Mean annual precipitation (mm)	900-800	800-600	600-400	400-250	-	250<
Mean temp. of bud development (°C)	14-16	14-19	19-22	22-25	-	25>
	14-12	12-10	10-7	7-4	-	4<
Mean min. temp. of flowering stage (°C)	20-25	25-27	27-29	29-32	-	32>
	20-18	18-15	15-10	10-0	-	0<
Relative humidity of flowering stage (%)	40-60	60-65	65-70	>70	-	-
	40-30	30-25	25-20	<20	-	-
Mean temp. of growing cycle (°C)	20-25	25-27	27-29	29-35	-	-
	20-17	17-14	14-12	12-10	-	-
Mean temp.of fruit formation and ripening Stage (°C)	23-22	22-20	20-17	17-15	-	15<
	23-24	24-25	25-30	30-35	-	35>

The square root approach (Equation 1) was used to generate the climatic index, which was subsequently transformed into a climatic appropriateness grade using mathematical formulas (ZeynaldiniMimand *et al*., 2019). Equation 2 is used to compute the climatic grade in cases where the climatic index is less than 25. Equation 3 is used to determine the climatic grade when the climatic index is more than or equal to 25 but less than 92.5.

Table 3. Climatic class, climatic index and limitation level

Climatic class	Climatic index	Limitation level
S0	87.5-100	Without limitation
S1	75-87.5	With low limitation
S2	50-75	With medium limitation
S3	25-50	With severe limitations
N1	12.5-25	With very severe surmountable limitations
N2	0-12.5	With very severe permanently limitations

$$CI = R_{\min}\sqrt{A/100 \times B/100 \times C/100 \ldots\ldots} \quad (1)$$

$$CR = 1.6 \times CI \quad (2)$$

$$CR = 16.67 + 0.9 \times CI \quad (3)$$

In this formula, **A**, **B**, **C**, etc., represent the suitability scores for each of the climatic variables, and **R_min** represents the minimum suitability score. Additionally, **CI** refers to the climatic index, and **CR** represents the climatic suitability grade. Based on the calculated climatic index, the information was classified into six climatic suitability classes: **S0**, **S1**, **S2**, **S3**, **N1**, and **N2**, which correspond to no limitation, slight limitation, moderate limitation, severe limitation, very severe limitation (modifiable), and very severe limitation (non-modifiable), respectively (Table 3). Finally, a climatic suitability map was created for almond trees for the three different varieties (early-flowering, mid-flowering, and late-flowering) at the provincial level.

2.3. Determination of the Growing Season

Given that the purpose of this study is to evaluate the climate appropriateness for rainfed almonds, meteorological data from multiple weather stations around the province was used to establish the growing season in the study area. Data on potential evapotranspiration, half of the potential evapotranspiration, and monthly rainfall were used in a graphical way to do this. According to FAO (1983), the growing season is the time of year when temperature and moisture levels permit agricultural production. The growing season, whose duration is determined by the weather, is a period of time when the temperature and moisture content are suitable for agricultural output. Four sub-periods make up a typical growing season, as defined by the FAO in 1983:

1. Start of the growing season: Rainfall is less than potential evapotranspiration but more than half of it.
2. Wet period: Rainfall exceeds potential evapotranspiration.
3. End of the rainy season: Rainfall falls between the total potential evapotranspiration and half of it.
4. Storage period or end of the growing season: Rainfall is less than half of the potential evapotranspiration, and the plant relies on stored soil moisture.

Four categories of growing seasons are defined by the FAO (1983): Normal growing season: This season includes the four sub-periods mentioned earlier.

1. Intermediate growing season: In this scenario, the wet sub-period is absent, leading to no water storage in the soil, which results in plants facing water shortages.
2. Wet growing season: All year long, there is more rainfall thanevapotranspiration.
3. Dry growing season: Rainfall falls below half of the annual potential evapotranspiration during this time.
4. In areas where such conditions prevail, there is no growing season in terms of moisture, and rainfed agriculture is not feasible.

3. Results and Discussion

The growth curves based on data from the weather stations in Shahrekord, Kuhrang, Lordegan, and Borujen are presented in Figure 1 (due to the similarity of growth curves in other stations, those graphs have not been included). According to the data extracted from these graphs, the moisture growing season is as follows: in Shahrekord, it lasts from 6ndNovember to 2ndJune; in Kuhrang, from 20ndOctober to 12ndJuly; in Lordegan, from 2ndNovember to 18ndJune; and in Borujen, from 14ndNovember to 8ndJune.The analyzed stations display both a wet phase and the conclusion of the rainy season, as illustrated in Figure 1, suggesting that the growth season is of the typical type. However, the short wet season in some places, including Shahrekord and Borujen, presents difficulties for rainfed agriculture there.

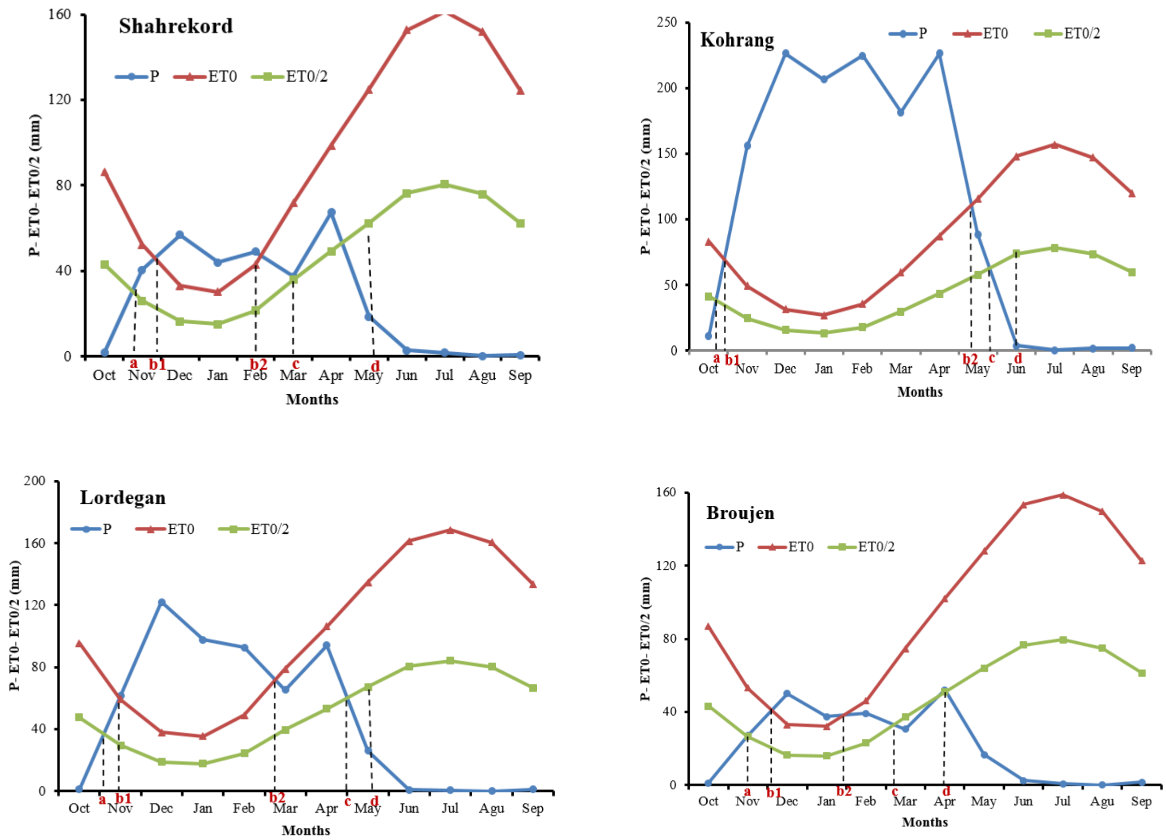

Fig. 1. The growth curve based on data from different climatic stations in Chaharmahal and Bakhtiari Province (ab1: beginning of the growth period, b1b2: wet period, b2c: the end of the rainy season, cd: the end of the growth period)

Table 4 shows the area and percentage of climatic appropriateness classes for several rainfed almond types. The climate of the region poses severe to very severe limitations for the cultivation and development of this variety, according to the results of the climatic suitability assessment for early-flowering varieties. Over 53.3% of the province is classified as having very severe limitations, meaning it is not suitable for planting this type of variety. Therefore, it can be said that climatic condition should be considered for site selection to avoid flowering failure and flowering damage associated with un-favorable weather conditions during this sensitive stage. The main limiting environmental factor that results in this variety's incorrect classification is the average minimum temperature during the flowering stage. Temperature is one of the most important climatic factors, as it greatly affects whether a location is ideal for growing a certain plant or not. The absolute minimum and maximum temperatures, the average number of frost days, and other temperature-related information are examples of temperature parameters. These plant-dependent characteristics are measured over the course of the year or for a designated length of time during the growth season (ZeynaldiniMimand *et al*., 2019). Among all the meteorological variables affecting the development of agricultural crops, temperature is probably the most important since its variations at any scale set the boundaries of all stages of plant development (Serrano-Notivoli *et al*., 2020).

Figure 2 displays the province's climatic suitability map for early-flowering almond types. According to this map, most districts in the province, including Shahrekord, Borujen, and parts of Kiar, Farsan, and Kuhrang, fall under the suitability class N2. The other districts in the province exhibit severe limitations for the cultivation and development of this tree. In these districts, the average minimum temperature during the flowering stage continues to be a limiting factor for the climatic suitability of this variety, although its impact is less pronounced compared to other districts. Numerous studies have indicated the sensitivity of the almond crop to temperatures during the flowering stage (Miranda *et al*., 2005; Kodad *et al*., 2010).

It is crucial to note that considering the annual rainfall and its uneven distribution throughout the year, cultivation of this product as rainfed in districts classified as S3 should be undertaken cautiously. The planting arrangement of trees (density of trees per hectare) must be determined with care. If this product is grown as rainfed, supplemental irrigation or the use of rainwater harvesting techniques will be essential due to the length of the rainfall period. Otherwise, the crop will face water shortages, leading to a significant reduction in yield.

Table 4. Area and percent of climatic suitability class for different cultivars of rainfed Almond

Cultivar type	Suitability class	Area (ha)	Percent
Early-flowering (Sefied)	With severe limitations (S3)	762314.4	46.7
	With very severe permanently limitations (N2)	871362.6	53.3
Mid-flowering (Mamaei and Rabie)	With severe limitations (S3)	934135.7	57.2
	With very severe surmountable limitations (N1)	372074.5	22.8
	With very severe permanently limitations (N2)	327466.8	20
Late-flowering	With severe limitations (S3)	1427299.7	87.4
	With very severe permanently limitations (N2)	206377.9	12.6

The results of the climatic suitability assessment for rainfed almond trees (mid-flowering varieties) using the parametric method in Chaharmahal and Bakhtiari province indicate that the region's climate exhibits diversity for the cultivation and development of mid-flowering almond varieties. This includes classes with severe limitations, very severe limitations that are amendable, and very severe limitations that are not amendable. According to the results obtained, 57.2% of the province's lands fall under the climatic suitability class S3 for this type of variety (Table 4). The average minimum temperature during the flowering stage is identified as the most limiting climatic parameter for planting this variety in the province. The majority of the province's districts are categorized as S3 for the development and cultivation of mid-flowering types, according to the climatic suitability maps that were produced. Although there are extremely severe climate constraints in Borujen and sections of Kuhrang, these limitations are amendable. In contrast, some areas of Shahrekord and Kiar are categorized as N2. It is feasible to raise the climatic adaptability class to S3 in these districts by implementing frost mitigation techniques and using proper management practices (Figure 3).

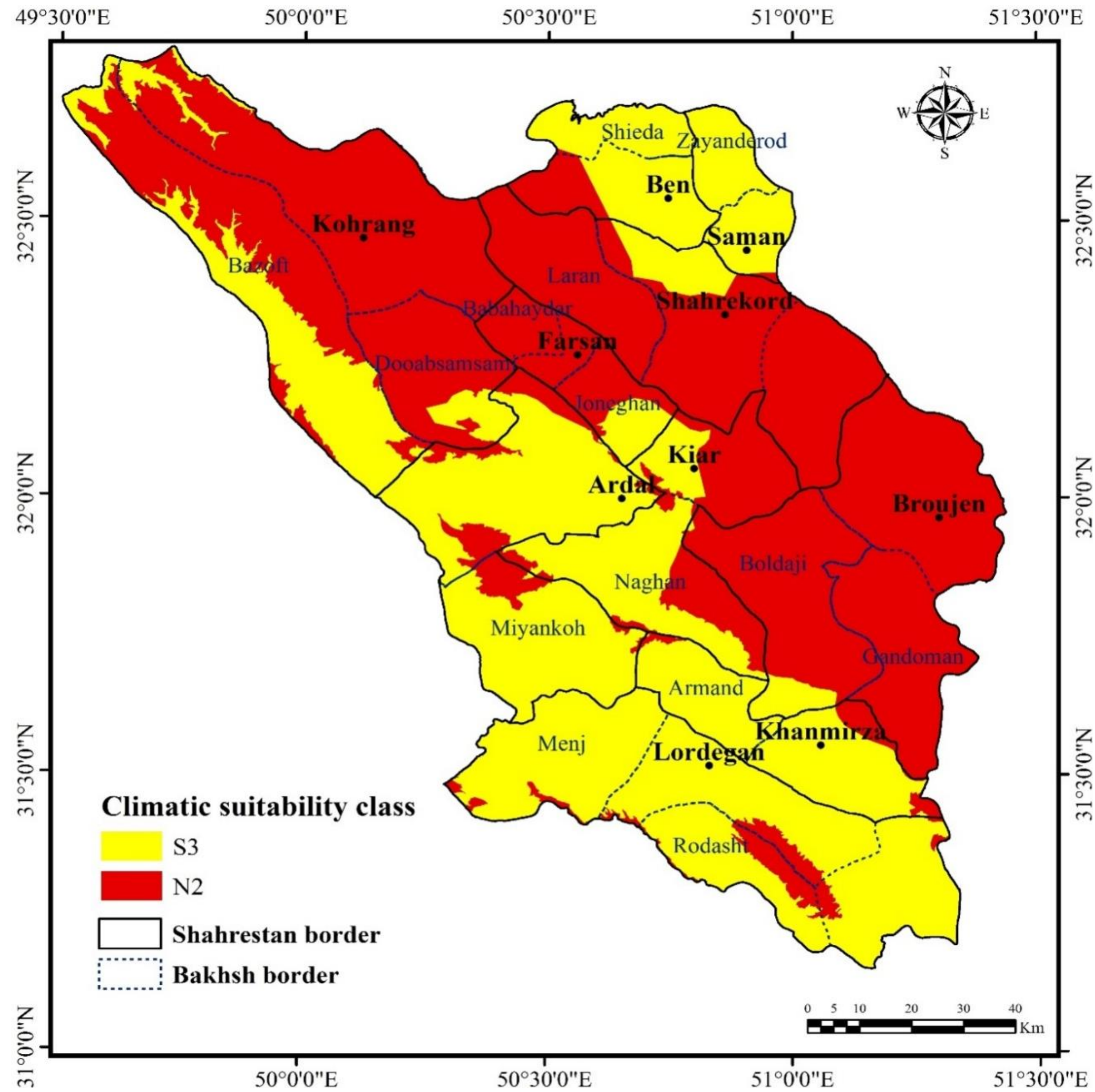

Fig. 2. Climatic suitability map for rainfed Almond- early-flowering cultivar

The results of the climatic suitability assessment for rainfed almond trees (late-flowering varieties) using the parametric method in Chaharmahal and Bakhtiari province indicate that the region's climate poses severe limitations for the cultivation and development of rainfed almond trees (late-flowering varieties) (Table 4 and Figure 4). The findings reveal that a significant portion of the province (87.4%) falls under the suitability class S3 for the planting and development of this crop (Figure 4). The minimum temperature during the flowering stage is identified as the most critical limiting climatic parameter.

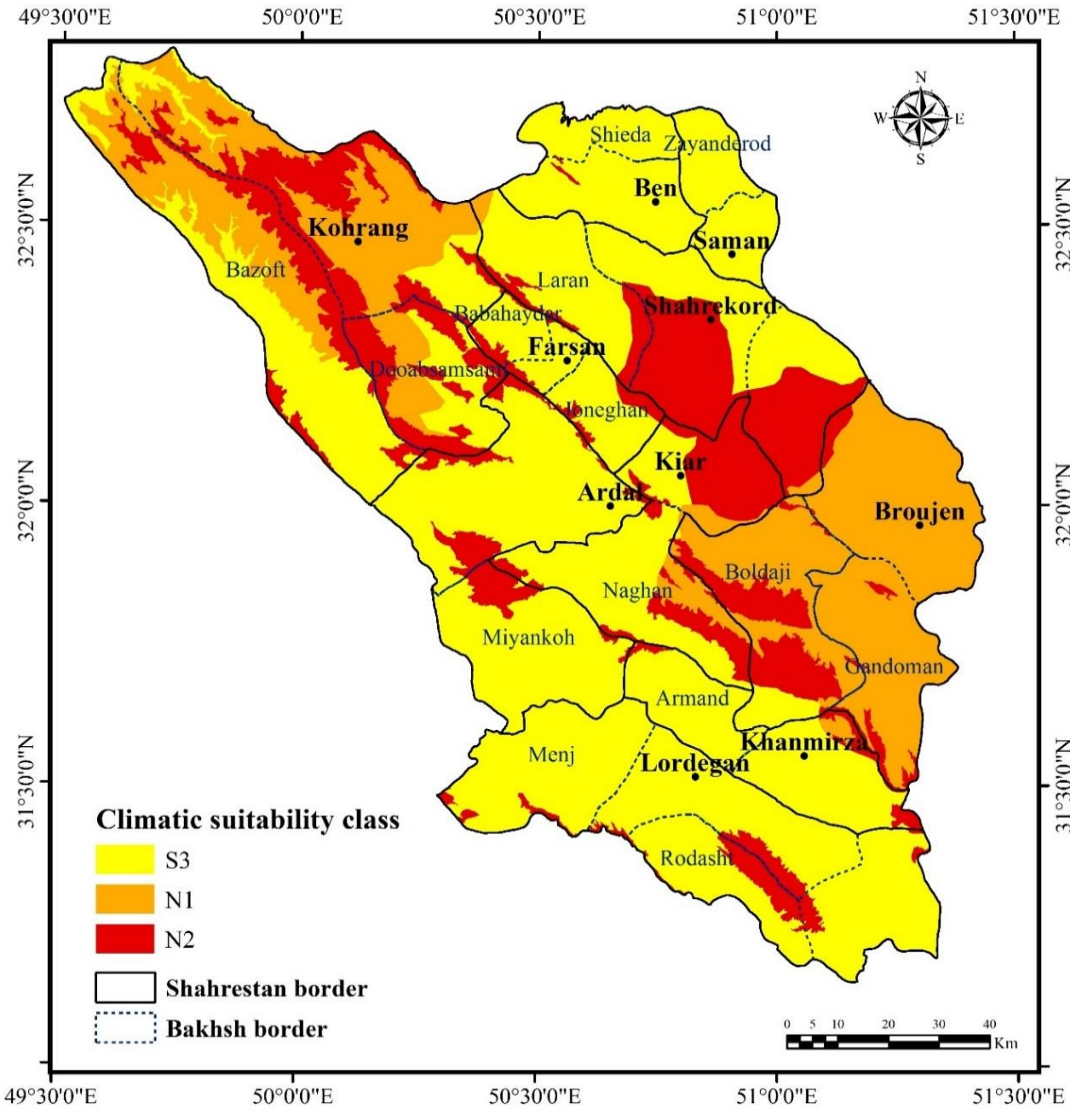

Fig. 3. Climatic suitability map for rainfed Almond- mid-flowering cultivar

The climate of each region, particularly factors such as minimum temperature and rainfall distribution, can have varying effects on plant growth, and these effects are especially pronounced for different almond varieties. The occurrence of late spring frost, as one of the most significant limiting factors for the production of this crop, underscores the importance of carefully managing the selection of varieties and implementing climate-oriented strategies. As the results indicated, late-flowering varieties, due to their better timing in dealing with cold, can help mitigate damage caused by frost. This is particularly crucial in areas with unstable temperatures during the spring. Martínez-Gómez *et al*. (2017) explained that the development of cultivars with late flowering achieved delayed flowering dates (around 15 days compared to traditional Spanish cultivars), can reduce damage caused by frost and improved agronomic performance.

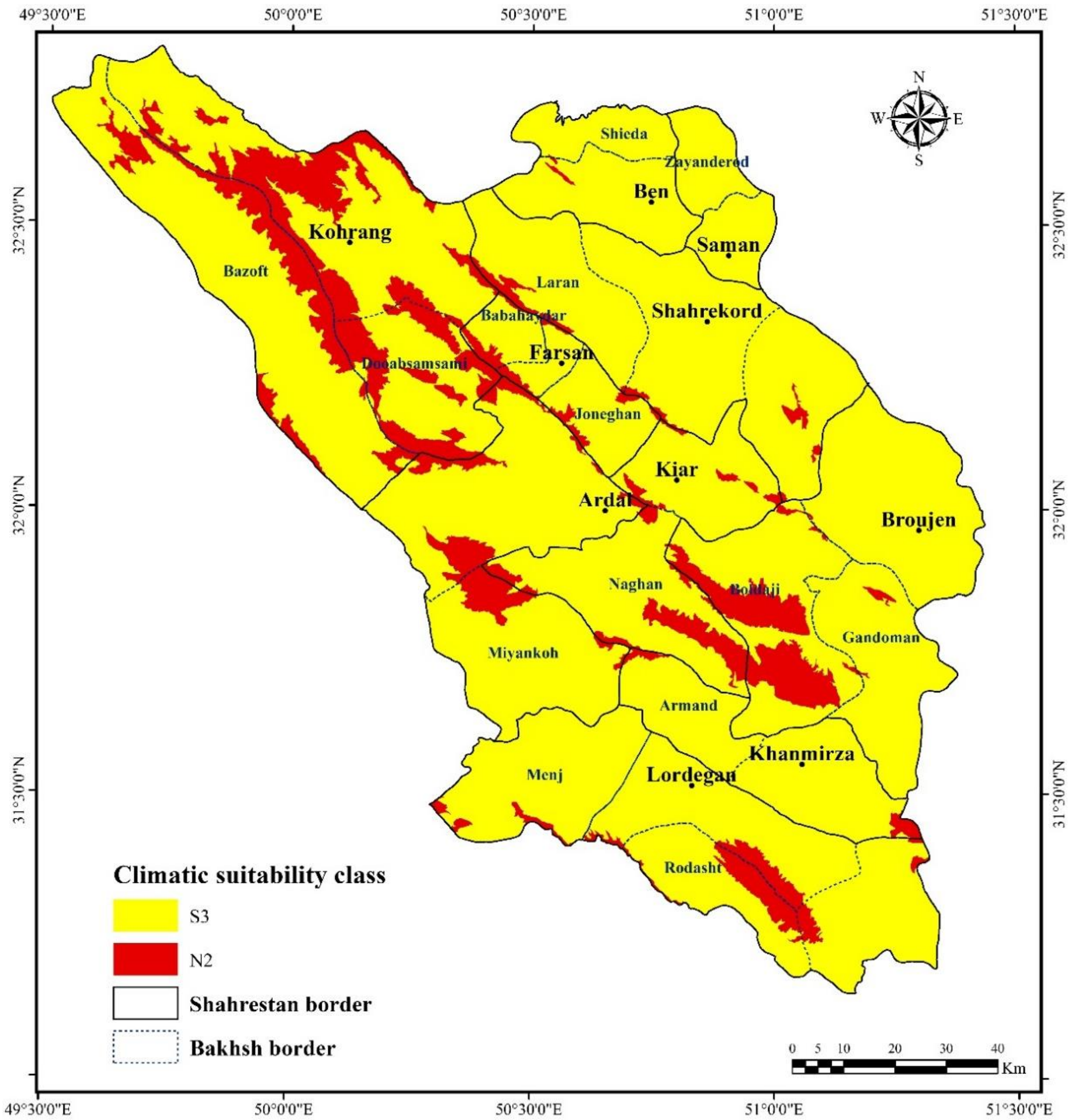

Fig. 4. Climatic suitability map for rainfed Almond- late-flowering cultivar

In addition to temperature management, the overlap between the plant growth period and the region's climatic cycle also plays a vital role in the final product yield. The findings of this study reveal that the growth cycle of almonds does not fully align with the climatic growth periods of the region, and this mismatch is exacerbated under conditions of irregular and uneven rainfall. This issue highlights that in many regions, rainfed almond cultivation without effective water resource management, such as using rainwater harvesting techniques or surface water storage, may face failure. In such circumstances, insufficient access to water during critical growth periods can lead to a significant decrease in yield, resulting in reduced economic returns from almond cultivation.

4. Conclusion

The finding of this study make it abundantly evident how cultivar type affects almond crop production. As a result, a region's climate and appropriateness vary not only for individual plants but also for different cultivars of the same plant. In every part of the province, late spring frost is a limiting factor for this plant's growth. A comparison of the obtained maps indicates that this problem can be significantly controlled and production reduction can be avoided by using late-flowering varieties. In the province, the minimum temperature during the flowering stage is a very determining and limiting factor for this product. With regard to late-flowering cultivars, it should be mentioned that a 40% yield drop in comparison to optimum conditions should be taken into consideration in different parts of the province based on the meteorological conditions.

The results also indicate that the share of unsuitable classes in late-flowering cultivars decreases by 17.8% and 16.8%, respectively, compared to early-flowering and medium-flowering cultivars. Additionally, based on the phenology of the almond tree, it can be inferred that the growth cycle of these crops does not completely overlap with the climatic growth periods of the region. Therefore, considering annual rainfall, the uneven distribution of rainfall throughout the year, and the incomplete overlap of the growth periods with the growth cycles of these crops, complete dryland cultivation of these products is not recommended. If this product is cultivated in dryland conditions, the use of rainwater harvesting methods for meeting water requirements becomes essential. Otherwise, the crop will face water shortages, leading to a significant reduction in yield.

Author Contributions

Conceptualization, Zohreh Mosleh Ghahfarokhi and Asghar Mousavi; methodology, Zohreh Mosleh Ghahfarokhi; software, Zohreh Mosleh Ghahfarokhi; validation, Asghar Mousavi; formal analysis, Asghar Mousavi; investigation, Zohreh Mosleh Ghahfarokhi; resources, Zohreh Mosleh Ghahfarokhi and Asghar Mousavi.; data curation, Asghar Mousavi.; writing—original draft preparation, Z.M.; writing—review and editing, Asghar Mousavi; visualization, Asghar Mousavi. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

Data available on request from the authors.

Funding

The study was funded by the Agricultural Jihad Organization of Chaharmahal and Bakhtiari Province, and Grant No. 33.30921.

Conflict of interest

The authors declare no conflict of interest.

References

Ahmadi, H., Falah Ghalhari, GH. (2015). The agroclimatic classification of northern east of Iran based on thermal and humidity conditions. *Journal of Agricultural Meteorology, 3(1),* 67-81.

Bagheri Bodaghabadi, M., Ebrahimi Meimand, F., Mehnatkesh, A., Mousavi, A. (2020). Evaluation of Land Suitability for Horticultural Use Case Study: Saman County, Chaharmahal and Bakhtiari Province. *Geography and Environmental planning, 31 (1),* 53-72.

Daccache, A., Ciurana, J.S., Rodriguez Diaz, J.A., Knox, J.W. (2014). Water and energy footprint of irrigated agriculture in the Mediterranean region. *Environmental Research Letters, 9 (1)* 124014. https://doi.org/10.1088/1748-9326/9/12/124014

FAO, 1983. Guidelines: Land Evaluation for Rainfed Agriculture. FAO Soils Bulletin No. 52. Rome, FAO.

Hansen, J.W. (2002). Applying seasonal climate prediction to agricultural production. *Agricultural Systems, 74 (3),* 305- 307. https://doi.org/10.1016/S0308-521X (02)00042-2

Javadi, z., Fallah Ghalhari, GH., Entezari, A. (2014). The role of climatic parameters on yield of almond Case Study: Sabzevar. *Journal of Climate Research, 17&18 (1),* 125-141.

Kodad, O., Sociasi Company, R., Morales, F. (2010). Evaluation of almond flower toleranceto frosts by chlorophyll fluorescence. *Options Méditerranéennes, 94,* 141–145.

Kumar, A., Mahapatra, S. K. & Surya, J. N. (2021). Soil Suitability of Some Major FruitCrops for Sustainable Production in the IGP Region of India-A Case Study. *Biological Forum – An International Journal, 13(1),* 200-210.

Lorite, I.J. Cabezas-Luque, J.M., Arquero, O., Gabaldón-Leal, C., Santos, C., Rodríguez, A., Ruiz-Ramos, M., Lovera, M. (2020). The role of phenology in the climate change impacts and adaptation strategies for tree crops: a case study on almond orchards in Southern Europe. *Agricultural and Forest Meteorology, 294,* 108142. https://doi.org/10.1016/j.agrformet.2020.108142

MaghamiMoghim, F., Karimi, A., Haghnia, GH., Dourandish, A. (2013). Evaluation of land use and suitability for rainfed crops in Roin, North Khorasan. *Journal of Agroecology, 5(2),* 143-152.

Martínez-Gómez, P., Prudencio, A.S., Gradziel, T.M., Dicenta, F. (2017). The delay of flowering time in almond: a review of the combined effect of adaptation, mutation and breeding. *Euphytica, 213,* 1997. https://doi.org/10.1007/s10681-017-1974-5

Miranda, C., Santesteban, L.G., Royo, J.B. (2005). Variability in the relationship between frost temperature and injury level for some cultivated Prunus species. *HortScience, 40 (2),* 357–361. https://doi.org/10.21273/HORTSCI.40.2.357

Niu, J., Liu, Q., Kang, S., Zhang, X. 2018. The response of crop water productivity to climatic variation in the upper-middle reaches of the Heihe River basin, Northwest China. *Journal of Hydrology, 563 (1),* 909- 926. https://doi.org/10.1016/j.jhydrol.2018.06.062

Pope, K.S., Da Silva, D., Brown, P.H., DeJong, T.M. (2014). A biologically based approach to modeling spring phenology in temperate deciduous trees. *Agricultural and Forest Meteorology, 198-199,* 15–23. https://doi.org/10.1016/j.agrformet.2014.07.009

Serrano-Notivoli, R., Tomás-Burguera M., Martí, A., Beguería, S. 2020. An integrated package to evaluate climatic suitability for agriculture. *Computers and Electronics in Agriculture, 176,* 105473. https://doi.org/10.1016/j.compag.2020.105473

Seyedmohammadi, J., Delsouz Khaki, B., Ebrahimi Meymand, F., Mohammad Esmail, Z., Kharazmi, R., Bagheri Bodaghabadi, M. (2024). Climatic suitability evaluation for Some Horticultural crops, (Case Study: Makou-Shout County, West Azerbaijan). *Journal of Range & Watershed Management, 76(4),* 427-440.

Shojaee, T., Fallah Ghalhari, GH., Kashki, A. (2020). Evaluating the Ability of Grapevine Cultivation in Iran Based on Climatic Conditions. *Journal of Water and Soil, 33(6),* 923- 942.

Yan, Z., Zhang, X., Adil Rashid, M., Li, H., Jing, H., Hochman, Z. (2020). Assessment of the sustainability of different cropping systems under three irrigation strategies in the North China Plain under climate change. *Agricultural Systems, 178 (1),* 102745. https://doi.org/10.1016/j.agsy.2019.102745

Yarahmadi, J., Amini, A., Rostamizad, GH. (2023). Accuracy Assessment of Pistachio Climate Suitability Map Based on ROC Curve. *Environment and Water Engineering, 9(1),* 127-140.

ZeinadiniMeymand, A., Toomanian, N., Navidi, N., Farajinia, A., Seyed Jalali, A. (2019). Horticultural crops requirements. Soil and Water Research Institute.