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Climatic Suitability of Growing Summer Squash (*Cucurbita pepo* L.) as a Medicinal Plant in Iran

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Abstract

Diversification of production by including a broader range of plant species, can significantly contribute to improve health and nutrition, livelihoods, household food security and ecological sustainability. Exploring the climate impact on any given crop is one of the first priorities to find new suitable areas for production and management of new crops. Summer squash (*Cucurbita pepo* L.) is an economically valuable plant with various medicinal potentials. In order to investigate summer squash cultivation feasibility under Iran's climate, three main agricultural regions (Azerbaijan, Khorasan and central part of Iran (Fars and Isfahan)) were selected. These regions suitability for summer squash cultivation were evaluated by considering three vital climate variables encompass temperature, precipitation, and sunshine hours. These regions show distinct and representative climatic conditions of Iran. Annual and growing season average of maximum, minimum, mean temperature, precipitation, and sunshine hours were calculated (May-September) for all locations with 44 years historical weather data (1961-2005) for 8 locations (Oroomieh, Tabriz, Khoy, Mashhad, Sabzevar, Birjand, Shiraz and Isfahan), 39 years (1966-2005) for 2 locations (Kashan and Fassa), 28 years (1977-2005) for 4 locations (Ardebil, Abadeh, Bojnurd and Shargh Isfahan) and 20 years (1985-2005) for 9 locations (Mahabad, Sarab, Maragheh, Parsabad, Khalkhal, Ferdous, Ghaen, Kashmar and Sarakhs). Climatic demands of summer squash were determined by four years field studies at four different locations in Iran. Our results showed Azerbaijan region has a suitable condition for this crop cultivation especially from precipitation and temperature perspectives. Central part of Iran and Khorasan were also found as partly suitable locations however as they are near to deserts with hotter and drier climate, there might be some other crops considered as priorities in these areas.

Keywords: climate factors, medicinal plants, plants climatic suitability, plants growth, summer squash (*Cucurbita pepo* L.)

Introduction

In recent decades, great attention has been focused to the concept of sustainable economic systems including the valorization of local biomass (Tre and Deboer, 2005). Medicinal plants are in use by many people in developing countries, considering their low costs, effectiveness, the frequently inadequate provision of modern medicine, and cultural and religious preferences (Shanley and Luz, 2003). The annual global market for herbal remedies, estimated at approximately US$ 23 milliard, makes a considerable contribution to the economy of producer countries (Andel and Havinga, 2008). The global population is nowdays over-dependent on a few plant species. Diversification of production by including a broader range of plant species can significantly contribute to improve health and nutrition, livelihoods, household food security and ecological sustainability. In particular, many of underutilized plant species offer enormous potential in combating hunger and offering medicinal and income generation options. Due to over-exploitation and habitat degradation, a number of wild medicinal and aromatic plants are facing possible extinction. The mounting demand for these plants necessitates domesticating and propagating them on a large scale (Bannayan *et al.,* 2006). Cultivation is frequently advocated as a measure to remove pressure from wild stocks, especially for species collected in large quantities for trade (FAO, 2006).

Among all human activities, agriculture is the most climate dependent (Bannayan and Hoogenboom, 2008). The concern on climate and its effects on agricultural productions have stimulated research on the analysis of climate and agricultural crop productivity (Bannayan *et al.,* 2010). It is realized that climate impose a wide range of direct and indirect impacts on crop production thus weather fluctuations play a significant role on crop growth and yield. Any change in local weather conditions especially during critical developmental stages of crops may adversely influence growth processes and result in enormous yield reductions.

Climate variables like temperature, solar radiation, rainfall, relative humidity and wind velocity, independently or in combination with each other influence crop growth and productivity (Pathak *et al.,* 2003). Multi-locations experiments are time and labor consuming, therefore agro-climatic studies for determining suitable regions for new crop cultivation is highly valuable (Azam *et al.,* 2001). Though climate is one of the main factors influencing plants selection, but mostly in the past, selection methods have often used simple classifications such as the Köppen system (Booth and Jovanovic, 2002). Data analyses

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techniques allow making descriptions of climatic requirements to be developed for individual plant species, rather than requiring species to fit within existing classifications (Booth, 1996).

The genus *Cucurbita*, indigenous to the western hemisphere, is comprised of five domesticated species (Whitaker and Davis, 1962). According to the FAO statistics information over 1,000,000 ha of summer squashs (*Cucurbita pepo* L.), squash (*Lagenaria vulgaris*) and some kind of gourds like figleaf gourd (*Cucurbita ficifolia*) and coyote gourd (*Cucurbita foetidissima*) and others, are harvested annually. Their total annual production is nearly 19,000,000 tons and only a small amount of this area and production is of summer squash (FAO, 2006). Summer squash is an economically important plant and is cultivated throughout the world for oil and medical purposes (Fu *et al.,* 2006). Pharmacological effects comprising antidiabetic, antihypertensive, antitumor, antimutagenic, immunomodulating, antibacterial, antihypercholesterolemic, intestinal antiparasitic, antalgic, and antiinflammation effects, and utilization possibilities of various summer squash species have been reported (Kostalova *et al.,* 2009). Seeds of summer squash (*Cucurbita pepo* L.) have long been used as a medicine for various ailments, particularly, as a treatment against worms (Lewis *et al.,* 1997). In Eritrea, Sudan and Ethiopia, summer squash seeds are used to treat tapeworm, when the dried seeds are eaten on an empty stomach. For many years, particularly in Europe, extracts from summer squash seeds, *C. pepo*, have been used in folk medicine as a remedy for micturition caused by Benign Prostatic Hyperplasia (Younis *et al.,* 2000). Summer squash is used for treating Helminth and as a medicine to reduce the bad cholesterol. There are no official data about summer squash cultivation lands in Iran but many Iranian farmers cultivate summer squash in marginal lands of their fields.

The characterization of phenological stages such as budding, flowering and fruit ripening is essential to achieve high seed quality and seed weight, since a number of management practices (irrigation, fertilizer, pesticide, and harvesting) rely on the recognition of certain phenological stages. There is no specific definition and established pheonological scale for summer squash. To increase the success rate and reduce the cost of restoration operations, it is essential to have a good understanding of their germination requirements (Fu *et al.,* 2006). Temperature can affect the percentage and the rate of germination (Roberts, 1988). According to Smith (1997), base temperature for summer squash (*Cucurbita pepo* L.) is 10°C while maximum growth is gained between 20°C to 25°C and ceiling temperature is 32°C; summer squash requires cooler temperature at night than during day. In temperate climates, semi determinate *Cucurbita* plants can reach the end of their exponential phase of their growth within 6 to 7 weeks from seeding. Maximum dry matter in fleshy fruit tissue usually occurs between 30 to 40 days after pollination in all three *Cucurbita* species (Brant-Loy, 2004). The number of female flowers per plant in two cultivars of summer squash (Maynard and Hochmuth, 1997) were highly reduced by lowering radiation levels to between 20% to 70% of full sunshine (Wien *et al.,* 2002). Our employed data are based on four years field experiment studies (Moazzen *et al.,* 2006; Jahan *et al.,* 2006; Gholipoori *et al.,* 2007; Bahrami *et al.,* 2009) which have locally determined the planting, harvesting dates, growth duration and climate conditions requirements of summer squash (*Cucurbita pepo* L.) in Iran (Tab. 1). Based on these studies the optimum planting date of summer squash is between May to September.

Water availability is second important factor, which affect summer squash yield (El-Keblawy and Lovett-Doust, 1996). Some of studies have already shown the critical developmental stages of summer squash (Whitaker and Davis, 1962; Wien *et al.,* 2002) (Tab. 2). Summer squash is sensitive to, and may be damaged by, excessive soil water from seed sowing to emergence. On the other hand, summer squash rooting depth is relatively shallow, soil water has to be maintained above 65% of the available soil water capacity in order to avoid detrimental water deficit (Ertek *et al.,* 2004). However as a forgotten plant, measured soil data of its local natural occurrence is quite scare. In this study, phenological stages including germination, rapid vegetative growth, flowering, pollination, fruit set start, fruit development and harvesting have been considered. All of these developmental stages require high level of sunshine. Thermal requirement for germination is 21-25°C, and at this stage, the plant does not need a high level of available water. Rapid vegetative growth requires 22°C-27°C thermal environment and high water availability. Flowering, pollination, fruit set start, fruit development and harvesting stages need 15°C-20°C, 15°C-20°C and 20°C-25°C range of temperature, respectively. Medium water availability during these three stages is in requirement to achieve optimum growth and yield of summer squash.

This study aims to find the most suitable location among 23 locations within the study regions in Iran for possible cultivation of summer squash based on climatic conditions.

Materials and methods

Monthly climate data of 23 locations, along 44 years (1961-2005) for 8 locations (Oroomieh ,Tabriz, Khoy, Mashhad, Sabzevar, Birjand, Shiraz and Isfahan), 39 years (1966-2005) for 2 locations (Kashan and Fassa), 28 years (1977-2005) for 4 locations (Ardebil, Abadeh, Bojnurd and Shargh Isfahan), 20 years (1985-2005) for 9 locations (Mahabad, Sarab, Maragheh, Parsabad, Khalkhal, Ferdous, Ghaen, Kashmar and Sarakhs) were obtained from Iran meteorology organization (IMO, 2009). Study locations consisted of three large regions including, Azerbaijan

Tab. 1. Field experiments data of summer squash studies in Iran

Studies	Treatments	Location	Altitude (meter)	LT	LN	GS	Precipitation (mm)	Tmax (°C)	Tmin (°C)	Seasonal temperature mean (°C)	Sunshine hours	Source
Exp 1	Plant densities and Phosphate levels	Ghazvin	1278	35.15	50	May-Sep	285	33.9	16.2	24.6	350	(Moazzen *et al.*, 2006)
Exp 2	Manure levels and branch management methods	Mashhad	999	36.16	59.38	May-Sep	234	32.9	18.6	24.7	349	(Jahan *et al.*, 2006)
Exp 3	Nitrogen levels and Head Pruning	Gorgan	13	36.51	54.16	May-Sep	679	32	22.6	26.8	214	(Gholipoori *et al.*, 2007)
Exp 4	Planting Methods and Head Pruning	Ardabil	1332	38.20	48.20	May-Sep	281	21.5	2	15.1	270	(Bahrami *et al.*, 2009)

LA, Latitude; LN, Longitude; GS, Growth season; Tmax, Mean of maximum temperature in growth season; Tmin, Mean of minimum temperature in growth season; Sunshine hours, sunshine hours in growth season

Tab. 2. Environmental factors requirement of summer squash at critical developmental stages

Growth critical stages	Germination	Rapid vegetative growth	Pollinate	Flowering and fruit set start	Fruit development and harvesting
Optimum temperature (°C)	21-25 (°C)	22-27 (°C)	15-20 (°C)	15-20 (°C)	20-25 (°C)
Optimum light duration	High	High	High	High	High
Water requirement	Low	High	Medium	Medium	Medium

Tab. 3. Climatic features of various study locations in Azerbaijan region

Location	LA	LN	Altitude (meter)	Annual precipitation (mm)	Tmax (°C)	Tmin (°C)	Seasonal temperature mean (°C)	Sunshine hours	Data period
Oroomieh	37.32	45.5	1313	324.6	27.5	12.87	20.3	327.8	1961-2005
Khoy	38.33	44.58	1103	295.8	29.2	13	22.2	298.4	1961-2005
Mahabad	36.46	45.43	1385	412.8	29.4	13.9	22.1	325.9	1985-2005
Tabriz	38.5	46.17	1361	289.7	29	16	22.3	320.8	1961-2005
Sarab	37.56	47.32	1682	242.2	25.8	8.5	17.6	318.8	1985-2005
Maragheh	37.24	46.16	1477.7	322.4	28.9	15.8	22.2	333.9	1985-2005
Ardebil	38.15	48.17	1332	306.8	23	9.42	16.5	263.2	1977-2005
Khalkhal	37.38	48.31	1796	384.6	23.4	9.1	17.3	321	1985-2005
Parsabad	39.39	47.55	31.9	268.1	30.2	17.5	24	254.6	1985-2005

LA, Latitude; LN, Longitude; GS, Growth season; Tmax, Mean of maximum temperature in growth season; Tmin, Mean of minimum temperature in growth season; Sunshine hours, sunshine hours in growth season

Tab. 4. Climatic features of various study locations in Khorasan region

Location	LA	LN	Altitude (meter)	Annual precipitation (mm)	Tmax (°C)	Tmin (°C)	Seasonal temperature mean (°C)	Sunshine hours	Data period
Mashhad	36.16	59.38	999	256.4	31.1	15	23.4	329.8	1961-2005
Sabzevar	36.12	57.43	977.6	192.1	34.5	19.7	27.7	323.7	1961-2005
Sarakhs	36.32	61.10	235	189.6	34.8	18.8	28.6	333	1985-2005
Bojnurd	37.28	57.19	1091	269.2	29.2	14.5	22.2	300.1	1977-2005
Kashmar	35.12	58.28	1109	204	33.6	19.9	28.4	338.7	1985-2005
Birjand	32.52	59.12	1491	169.6	33.3	16	25.6	333.3	1961-2005
Ghaen	33.43	59.10	1432	177.7	30.6	13.5	25.3	350.5	1985-2005
Ferdous	34.1	58.1	1293	147.7	34	18	28.3	347.3	1985-2005

LA, Latitude; LN, Longitude; GS, Growth season; Tmax, Mean of maximum temperature in growth season; Tmin, Mean of minimum temperature in growth season; Sunshine hours, sunshine hours in growth season

(Northwest of Iran), Khorasan (Southeast of Iran), Fars, and Isfahan (central part of Iran) (Fig. 1). These regions contain highly important agricultural lands in Iran. Each one of these regions character different climatic situations (Tab. 3, 4 and 5).

To calculate and define the most favorable climatic conditions for summer squash growth and development, various climate variables were considered. The categories and associated rating values for these ten different variables were listed as items (1) to (10) in Tab. 6 and 7. For

Tab. 5. Climatic features of various study locations in Fars and Isfahan region

Location	LA	LN	Altitude (meter)	Annual precipitation (mm)	Tmax (°C)	Tmin (°C)	Seasonal temperature mean (°C)	Sunshine hours	Data period
Shiraz	29.36	52.32	1488	328	35.1	17.3	27.2	335.8	1961-2005
Fassa	28.58	53.41	1288.3	309.8	37	18.5	29.3	329.4	1966-2005
Abadeh	31.11	52.40	2030	140.2	31.2	13.9	23.5	330.8	1977-2005
Isfahan	32.37	51.40	1550.4	120.7	33.2	17.9	25.9	329.5	1961-2005
Shargh Isfahan	32.40	51.52	1543	103.4	34	14.1	24	339	1977-2005
Kashan	33.59	51.27	982	137.8	37.1	21	30.2	305.8	1966-2005

LA, Latitude; LN, Longitude; GS, Growth season; Tmax, Mean of maximum temperature in growth season; Tmin, Mean of minimum temperature in growth season; Sunshine hours, sunshine hours in growth season

Tab. 6. Descriptive ranking of climatic factors by rating scores

Ranking	Temperature perspective (scores)	Precipitation perspective (scores)	Sunshine hours perspective (scores)	Overall
Suitable	19-24	15-20	10-12	41-60
Intermediate	15-18	10-14	4-8	36-40
Inappropriate	<15	<9	<4	<35

Tab. 7. Rating values for precipitation (mm)

Annual precipitation (1)	R	Precipitation during May-June (2)	R	Precipitation during July-Aug (3)	R	Precipitation during Sep (4)	R
<100	0	<10	0	<10	1	<5	1
100-150	2	10-15	0.5	10-15	2	5-10	2
150-200	4	15-20	1	15-20	3	10-15	3
200-250	6	20-25	1.5	20-25	4	15-20	4
250-300	8	25-30	2	25-30	5	20-25	5
>300	10	>30	2.5	>30	6	>25	6

R: Rating

Tab. 8. Rating values for growing season temperatures (°C) and sunshine hours

T max (5)	R	T min (6)	R	Mean temperature during May-Jun (7)	R	Mean temperature during July-Aug (8)	R	Mean temperature during Sep (9)	R	Sunshine hours (10)	R
<10	0	<10	0	<10	0	<10	0	<15	0	<100	0
10-15	2	10-15	2	10-20	2	10-15	2	15-20	2	100-200	4
15-20	4	15-20	4	20-27	6	15-20	6	20-25	6	200-300	8
20-27	6	20-27	6	27-32	1	20-25	3	25-30	2	300-400	12
27-32	2	27-32	2	-	-	>25	0	>30	0	-	-
>32	0	>32	0	-	-	-		-		-	-

R, Rating Tmax, Mean of maximum temperature in growth season; Tmin, Mean of minimum temperature in growth season; Sunshine hours, sunshine hours in growth season

example, a location with annual precipitation average of 123 mm would have received a rate 2 by this category of climate variable (1) (Tab. 7). The highest possible score for the sum of the optimum categories of all 11 variables is 60.5. This rating was employed based on plant requirements (Tab. 2) and farmer's indigenous knowledge. According to the regional field experiments (Brant-Loy, 2004; Whitaker and Davis, 1962; Wien *et al.,* 2002), temperature, water requirement, and sunshine hours showed the highest influence on summer squash growth respectively. Climatic scores were calculated based on such impact ranking of climate variables on the study crop; for instance, temperature has the highest impact on summer squash growth and development, especially during the pollination stage. On the other hand, each stage of growth requires specific range of temperature (Tab. 2). Hence, temperature with 28 scores was in first rank of variables, which affect summer squash growth. Precipitation with 24.5 scores, indicates a high effect on suitability of regions. Water deficit impact especially during the reproductive stage can enormously decrease any given crop economic yield, and water deficit is the most prominent limiting factor, which affects agricultural lands of Iran (Bannayan *et al.,* 2006). Climatic scores were developed for weather stations representative of irrigated agriculture regions in the Azerbaijan, Khorasan and central part of Iran (Fars and Isfahan). Each climatic regions are categorized by descriptive ranking (Tab. 6) based on its scores. To be more specific for considering the distinct climate differences within the regions and their possible different impact, Azerbaijan and Khorasan regions were sub-grouped to three divisions (West and East Azerbaijan and Ardabil for Azerbaijan regain, north and south of Khorasan and Razavi Khorasan for Khorasan region) and central part of Iran sub-grouped to two, Isfahan and Fars regions. Climatic scores were developed based on three climatic variables: (a) temperature (b) precipitation and (c) sunshine hours. These factors ranked by various scores (Tab. 7 and 8). Mapping system was performed by Arcview GIS 3.2 software (Breslin *et al.*, 1999).

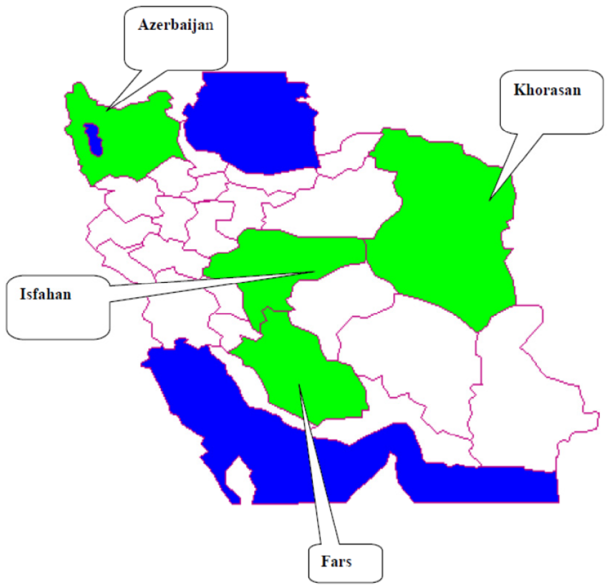

Fig. 1. Study regions in Iran

Results and discussion

Temperature

The range of scores for study regions based on temperature variable are shown in Fig. 2. Generally, Azerbaijan region indicated more favorable climatic suitability for cultivation of summer squash than other regions. This is more prominent as favorable thermal condition during flowering and pollination period, which are critical developmental stages in this plant's growth life. Temperature scores varied from 21 at Tabriz to 7 at Fassa. The average of temperature scores for each region was 17.5 for Azerbaijan 12.8 for Khorasan and 14 for central part of Iran. Temperature is the most important climate variable during summer squash life (Smith, 1997). Temperature shows a strong relationship with leaf emergence and number, the response of these parameters and production have been reported as a curvilinear relation. Moreover, flowering and pollination stages, and duration of development are also very sensitive to temperature (Whitaker and Davis, 1962).

Precipitation

The precipitation scores for all regions are shown in Fig. 3. Similar to temperature results, Azerbaijan region showed the highest scores among the studied regions, which might be due to its geographical location, as this area is more close to Caspian Sea compared to other regions. Central part of Iran and Khorasan regions are close to central desert in Iran. The highest value was obtained in

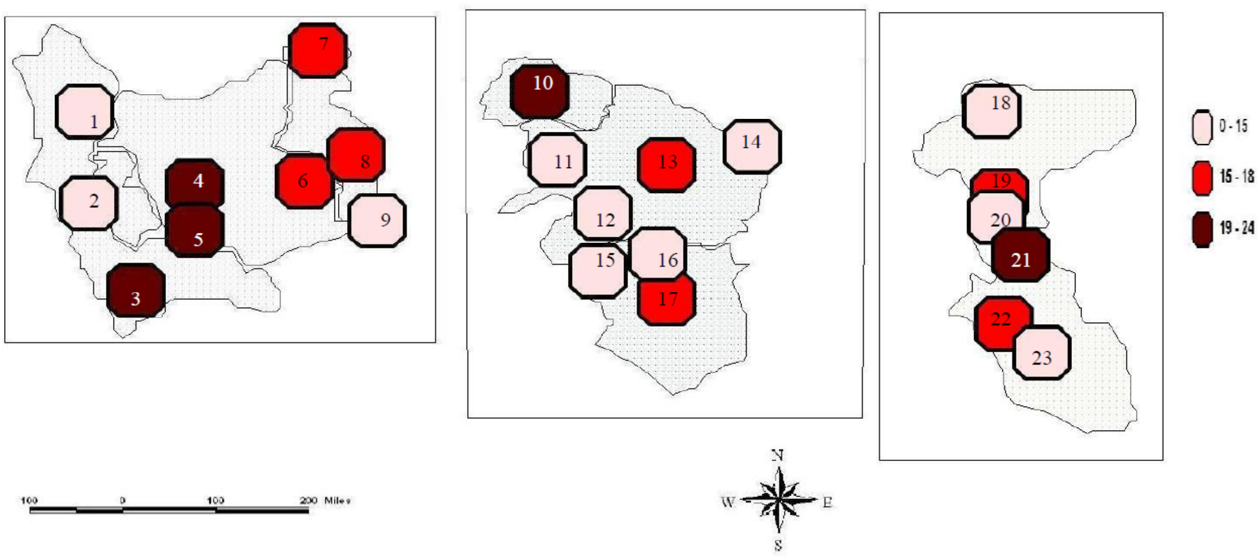

Fig. 2. Location rating based on temperature 1-Kooy; 2-Oroomieh; 3-Mahabad; 4-Tabriz; 5-Maragheh; 6-Sarab; 7-Parsabad; 8-Ardebil; 9-Khalkhal; 10-Bojnurd; 11-Sabzevar; 12-Kashmar; 13-Mashhad; 14-Sarakhs; 15-Ghaen; 16-Ferdous; 17-Birjand; 18-Kashan; 19-Isfahan; 20-Shargh Isfahan; 21-Abadeh; 22-Shiraz; 23-Fassa

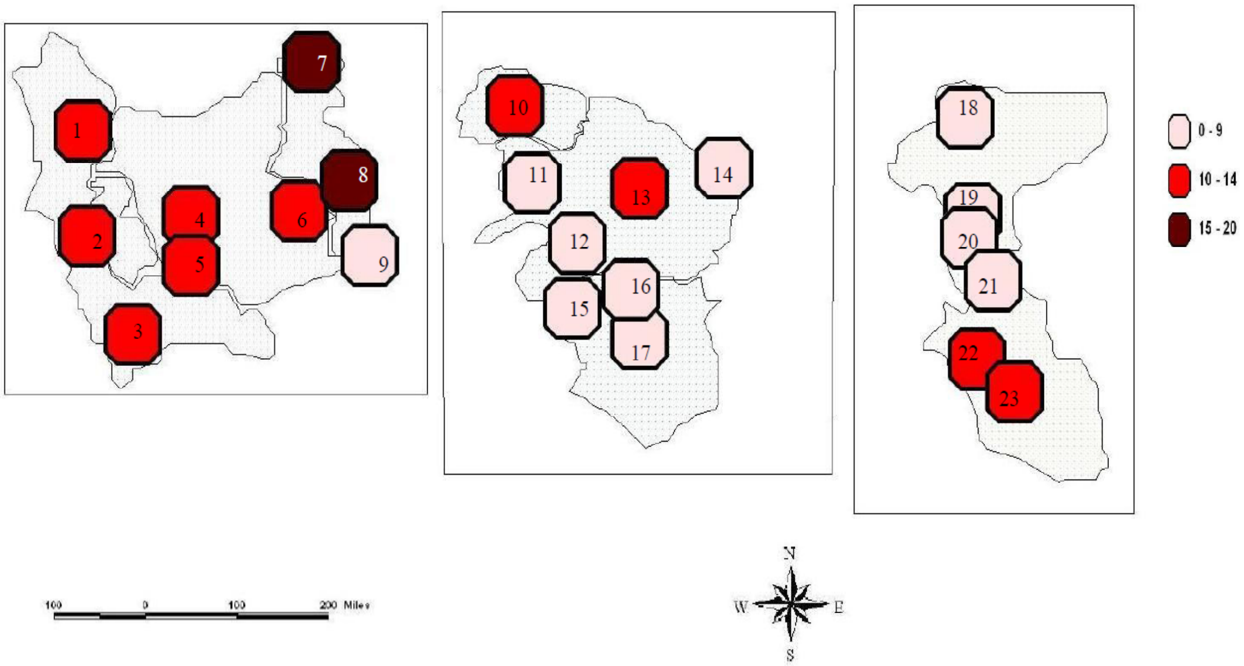

Fig. 3. Location rating based on precipitation. 1-Kooy; 2-Oroomieh; 3-Mahabad; 4-Tabriz; 5-Maragheh; 6-Sarab; 7-Parsabad; 8-Ardebil; 9-Khalkhal; 10-Bojnurd; 11-Sabzevar; 12-Kashmar; 13-Mashhad; 14-Sarakhs; 15-Ghaen; 16-Ferdous; 17-Birjand; 18-Kashan; 19-Isfahan; 20-Shargh Isfahan; 21-Abadeh; 22-Shiraz; 23-Fassa

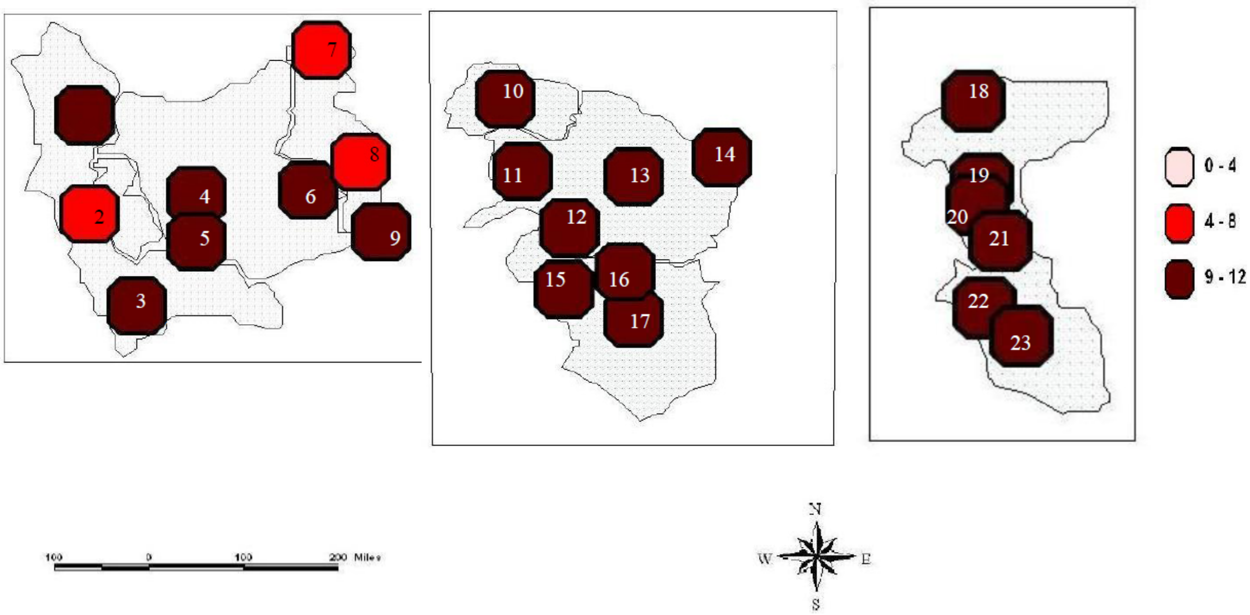

Fig. 4. Location rating based on Sunshine hour. 1-Kooy; 2-Oroomieh; 3-Mahabad; 4-Tabriz; 5-Maragheh; 6-Sarab; 7-Parsabad; 8-Ardebil; 9-Khalkhal; 10-Bojnurd; 11-Sabzevar; 12-Kashmar; 13-Mashhad; 14-Sarakhs; 15-Ghaen; 16-Ferdous; 17-Birjand; 18-Kashan; 19-Isfahan; 20-Shargh Isfahan; 21-Abadeh; 22-Shiraz; 23-Fassa

Parsabad location with 17.6, and lowest in the central part, as Isfahan and Kashan, with 4 scores.

Water is the second important factor, which affects summer squash yield (El-Keblawy and Lovett-Doust, 1996). Summer squash is sensitive to, and may be damaged by, excessive soil water from seed sowing to emergence (Whitaker and Davis, 1962). Since summer squash rooting depth is relatively shallow, soil water has to be maintained above 65% of the available soil water capacity in order to avoid detrimental water deficit (Ertek *et al.*, 2004)

Sunshine

The scores for all locations in the studied regions based on sunshine hours are shown in Fig. 4. The results did not show much deference between locations, compared to previous findings on temperature or precipitation, except

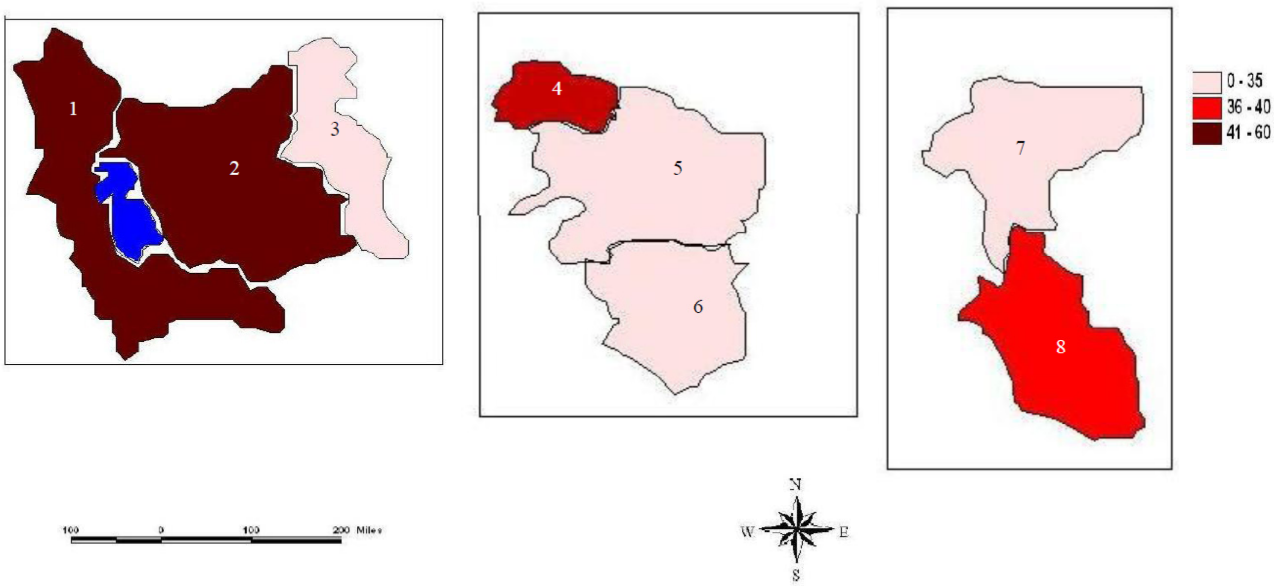

Fig. 5. Location rating based on all climate variables. 1-West Azerbaijan; 2-East Azerbaijan; 3-Ardabil; 4-north of Khorasan; 5-Razavi Khorasan; 6-south of Khorasan; 7-Isfahan; 8-Fars

for three locations in Azerbaijan. This might be due to the fact that these locations had a higher rate of precipitation and cloudy days than other locations. Sunshine duration and precipitation have an inverse relationship (Leemans and Cmmer, 1991). Our data showed that all of the investigated regions, except three locations in Ardebil and west Azerbaijan, had the highest score (12). Iran is located in an arid environment with low precipitation, thus it has few cloudy days, especially during summer. Sunshine duration is one of the most important determinants for the plant emergence, establishment, survival, and growth (Gray and Spies, 1996). The possible amount of growth, as measured by dry matter produced, depends directly upon the bright sunshine (Anderson Aldrich, 1933).

Overall perspective

The sum of the scores related to temperature, precipitation and sunshine hours are shown in Fig. 5. This study showed that Azerbaijan region indicated more suitability than other locations, especially due to higher precipitation. There was no tangible difference between study regions in terms of temperature and sunshine hours impact on summer squash. Azerbaijan is a mountainous area, but it provides the most suitable climatic requirements for the optimum growth of summer squash, including optimal range of water and temperature. Central part of Iran and Khorasan regions are dry areas and could not satisfy the summer squash water demand on a long period, as annual average precipitation of Azarbijan region is 316 mm, but for Central part of Iran and Khorasan regions are 200 mm and 189 mm respectively. The highest overall score was obtained in East Azerbaijan (44.3) and the lowest score was obtained in south of Khorasan (29.6).

Conclusions

Some agroclimatic features like temperature, precipitation, and sunshine hours are key variables for the optimum growth and sustainable yield of summer squash. Cultivation of marginal crops such as summer squash is a unique opportunity for increasing sustainability and biodiversity in agricultural lands. The employed approach in this study limited the number of important factors that can be used in the evaluation (e.g. soil data), but it enabled comparisons to be made between regions based on consistent climate data. The methodology provided an assessment of the climatic suitability of regions such as west part of Iran, Azarbaijan, where the crop is grown but quantitative evidence is scant, incomplete or inaccessible, and defines new regions not previously associated with this plant but where climatic factors indicate a potential for productive growth. Nevertheless, there remains considerable scope to find productivity of this plant by a clearer understanding of how factors such as the seasonal distribution of rainfall, day length, and range of temperatures influence the production and allocation of assimilates to seed yield. At this stage, our preliminary assessment allows planners to select promising locations, or regions that justify more detailed studies that bring local factors into the analysis and taking advantage of data of higher resolutions.

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