Global warming affected some morphological characters of Pistachio trees (*Pistacia vera* L.)

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Pistachio is one of the main horticulture crops in Iran where have the first cultivation and exportation position in the world. Climate change has already affected species distribution shifts in many parts of the world and more impacts are expected for the future, yet few studies have aimed for a general understanding of the regional basis for species vulnerability. In this research meteorology data of four months (December, January, February and March) from 1991 to 2008 and Phenology data of six pistachio cultivars that ranked in 3 groups: early flowering (Kalehghoochi and Ahmadaghaei), mid flowering (Momtaz and Amiri) and late flowering (Akbari and Shahpasand) during summer of 1997, 2001-5, and 2007 were studied in Kerman province. The evaluated factors included leaf area, normal and abnormal leaves. The results showed the mean of temperature on March has significant increasing during 1991 to 2008 and fluctuations between years increased after 1999 in December, January and February. Phenological characters including leaf area and number of normal and abnormal leaves were different each year that abnormality leaves in early and late flowering cultivars had negative correlation with mean temperature of December and mid flowering cultivars had positive correlation with mean temperature of February. The level of leaf area changing in Ahamadaghaei cultivar was less than other cultivars but kallehghoochi and Akbari had the highest range which can probably be a good marker for determining the effects of temperature changes in winter on production level.

Pistachio is one of the main products of Iran's exportation well-known in world wide markets. The plantation area of pistachio is more than 450000 hectares in Iran and any changing in growth factors even with trivial effects make huge change on production.

The phenology, physiology, distribution and interactions of plants mostly are determined by climate. Phenology is the study of the cycling of biological events throughout the year(3), and is considered the most responsive aspect of nature to climate warming (22).

The Earth achieves thermal equilibrium by balancing the net incoming solar radiation received from the Sun, with the infra-red radiation emitted back to space. This infra-red radiation is primarily blackbody radiation emitted by the Earth's surface and by clouds, but some infrared radiation is intercepted by the so-called atmospheric 'greenhouse gases' and absorbed at particular frequencies determined by their molecular structure. Only some of this absorbed energy is re-emitted by the greenhouse gases to space, the remainder acts to warm the planet. The concentrations of these greenhouse gases thus determine the equilibrium mean temperature of the atmosphere. A key greenhouse gas is carbon dioxide, CO_2 (12).

The impact of global climate change on plant distribution, speciation and extinction is of current concern. Global warming has affected whole cycle of plants and animals life with positive and negative effects (7, 13, 30).

Climate change has already triggered species distribution shifts in many parts of the world. Increasing impacts are expected for the future, yet few studies have aimed for a general understanding of the regional basis for species vulnerability (23, 30).

Global warming may disrupt ecosystem interactions because it alters these relationships and micro-evolution may be slow in tracking these changes. In particular, such shifts have serious consequences for ecosystem functioning for the tight multitrophic interactions involved in the timing of reproduction and growth (25).

Warm temperatures during winter have been causing lack of chilling and chilling requirements are not adequately satisfactory. Whereas in spring the phenological phases in high and mid-latitudes are considered to depend strongly on temperature conditions during winter and spring, the most important factors causing phase changes in autumn are not as clear (16).

Due to warm winter, many disorders reported such as dropping flower bud, underdevelopment of the pistil (20, 21, 27) delay on floral and leaf bud bursting (1, 5, 6, 8) Poor fruit set and low quality (1, 10, 11, 24) low cell division (10) irregular flowering and roset formation (11) smaller caliper, terminal shoot extension, leaf size and total plant height (2, 4, 29).

The predictions of climate models are still very uncertain, with the range of models available giving a wide variety of differing results (12, 28).

For many years human has cultivated for food and industry reliably but climate change has made the process unreliable for agriculture (9). Understanding the relative importance of climate change compared to other influences is important to the debate on whether limited funds should be directed to mitigation of climate change (i.e. emission reduction), or more local adaptation strategies (12).

In general, geographical differences in climate change and corresponding plant responses are quite common. (17).

Without some stresses, many perennial plants simply wouldn't survive. All stresses can change the hormonal balance in plants and surly climatical stresses are not out of this rule (14, 15).

Long-term surface data and remote sensing measurements indicate that plant phenology has been advanced by 2–3 days in spring and delayed by 0.3–1.6 days in autumn per decade in the past 30–80 years, resulting in extension of the growing season (18).

In this research we have tried to open a new window to effects of winter months (dormant months) on plant growth in which chilling requirement must be compensated in temperate fruits such as pistachio and find relations between climate change and phenological characters that may help us to determine a marker for recognizing resistant cultivars to climate changes.In these paper categories, use this tag after the bold first paragraph and after subheadings.

Studying on temperature data including mean, maximum and minimum of monthly temperature showed the mean of temperature on March had significant ($P \leq 0.01$) increasing during 1991 to 2008 and fluctuations between years increased after 1999 on December, January and February (fig. 1).

Phenological characters (leaf area and number of normal and abnormal leaves) were different each year including mid flowering cultivars (Amiri and Momtaz) had positive correlation with mean temperature of February, late flowering cultivars (Akbari and Shahpasand) and early flowering cultivars (Kallehghoochi and Ahmadaghaei)had negative correlation with mean temperature of December (Fig. 2-7). Leaf areas of cultivars were different in size and range of variation each year that cultivar of Ahmadaghaei had less changing in leaf area during the mentioned years (Fig. 8).

Recent winter temperature changing showed more fluctuation compared with last years and it has affected many plant species. In some plant species, these changes are adopted with optimum growth condition and caused to extend plantation areas and in some plant species it is vice versa (7, 13, 19, 26, 30).

The results showed different cultivars of pistachio follow special progress on abnormality of leaves. Leaves abnormality Percentage of early and late flowering cultivars have negative response to changing of December temperature and mid flowering cultivars have positive response to February temperature. Increasing temperature in short period in last month of winter (March) has forced buds of early flowering cultivars to be swollen and ready to burst but favorite condition doesn't continue and cold days maybe make stress on trees. This action probably is main reason to imbalance plant hormones and growth delay (14) in Kerman's plantation areas.

The late flowering cultivars due to warm winter especially on March are faced lack of chilling and these disorder signs observed on large scale in Kerman plantation area during recent years. The mid flowering cultivars are between early and late flowering cultivars therefore probably they have more adaptability with changing of temperature and show positive response to temperature changing.

The level of leaf area changing in Ahamadaghaei cultivar was less than other cultivars and kallehghoochi and Akbari had the highest range (Fig. 9).

During the recent years, production of kallehghoochi cultivar has been decreasing and many of the orchards are changed with ahmadaghaei cultivar by grafting. The results showed less changing on ahmadaghaei cultivar (Fig. 9) which can probably be a good marker for determining the effects of temperature on production level.

On a global scale, the composition and distribution of biomes is largely determined by climatic parameters. Indeed, there is evidence that climate change has already induced biome shifts (19, 26). Recent rapid climate change is already affecting a wide variety of organisms. Long-term data indicate that the anomalous climate of the past half-century is already affecting the physiology, distribution, and phenology of some species in ways that are consistent with theoretical predictions. Global climate changing is affected by many climatical and nonclimatical factors (light, photoperiod, temperature, precipitation, humidity, wind, as well as gases, topography, slope, exposure, soil properties, pests, diseases, and competition) but temperature is main factor and human activities are the main reason.

All data of this research and observation on pistachio plantation area in Kerman province have shown that the changing of climate makes force to replace sensitive cultivars with resistance and adopted cultivar in large scale by growers that can be considered in different areas by researchers and growers worldwide. Several studies have modeled future species distributions at regional and local scales and have extrapolated alarming extinction risks for the next century (6, 23). Regional studies of plant and animal phenology are extremely important, and due to the advantage of relatively low costs, once the data have been reported by volunteers, phenological studies can shed light on regional peculiarities (6).

Methods

Meteorology data of four months (December, January, February and March) were collected by synoptic station in Kerman city from 1991 to 2008. Phenology data gathered from 6 cultivars of pistachio that ranked in 3 groups: early flowering (Kalehghoochi and Ahmadaghaei), mid flowering (Momtaz and Amiri) and late flowering (Akbari and Shahpasand) during summer of 1997, 2001-5, and 2007 at Iran's pistachio research station No. 2 in Kerman province. The evaluated factors included leaf area, normal and abnormal leaves that were measured in three trees with four shoots per tree for different cultivars (Picture 1).

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Picture 1. Abnormal leaves in pistachio trees with one, two, four and misshape leaflets.

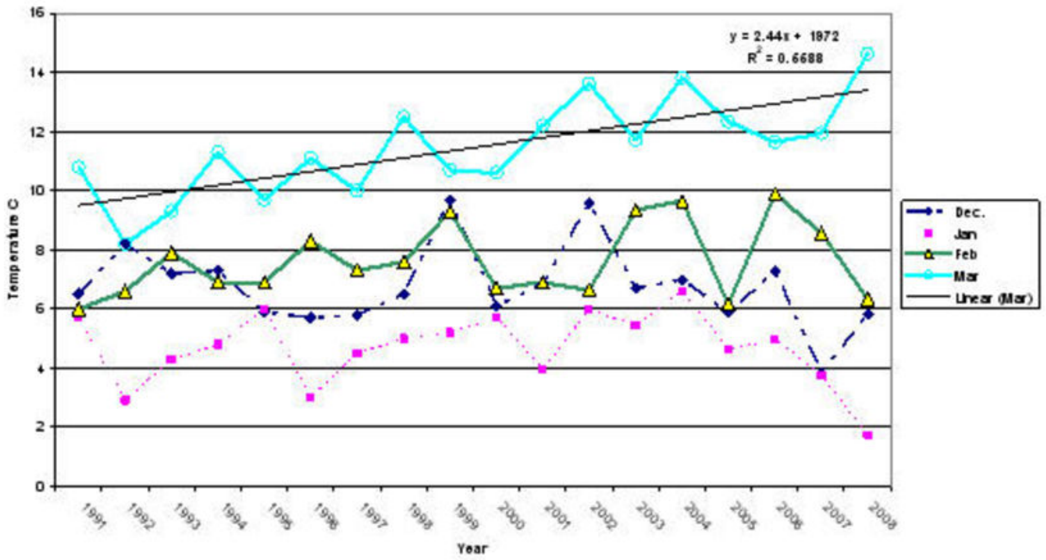

Figure 2. Mean temperature of December, January, February and March from 1991 to 2008.

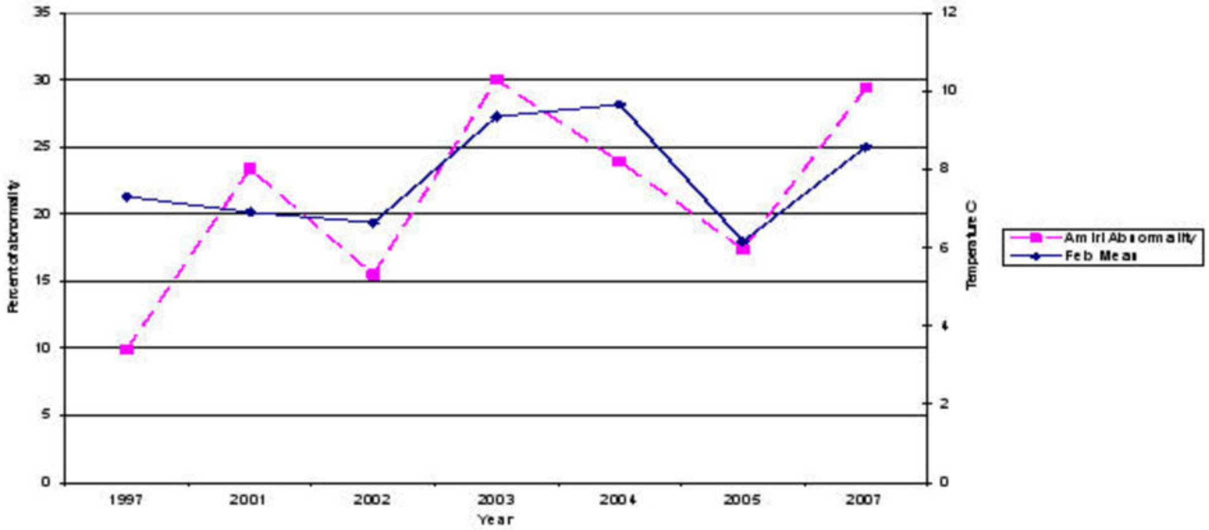

Figure 3. Positive correlation between percentages of abnormality and mean temperature in February on Amiri cultivar (mid flowering) during 1997, 2001-2005, and 2007 (P= 0.04).

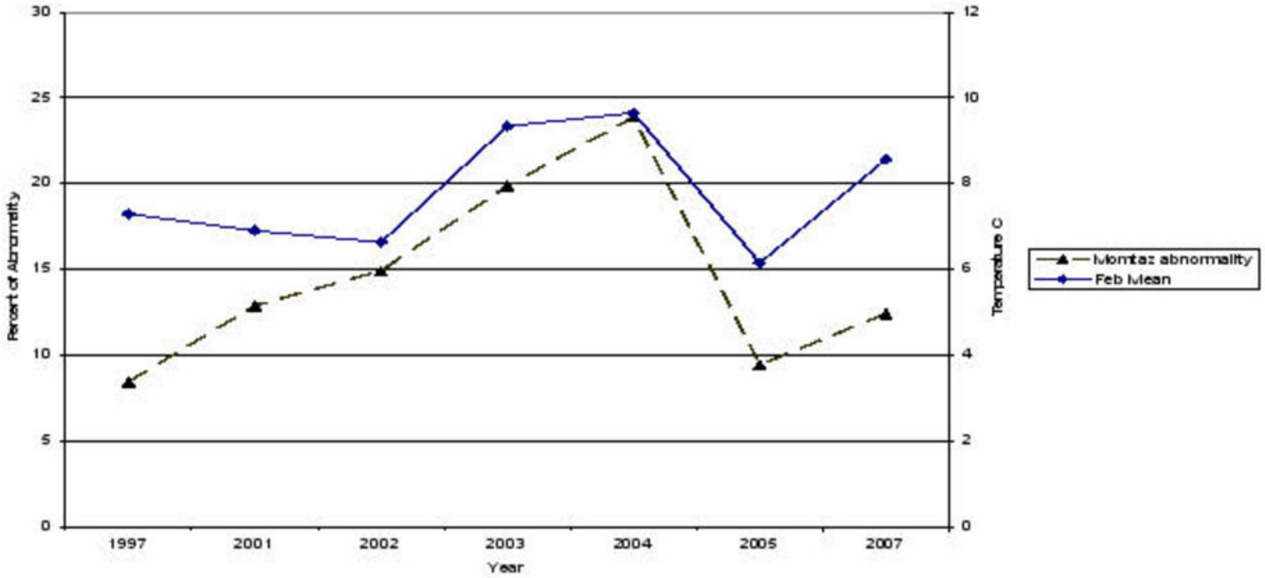

Figure 4. Positive correlation between percentages of abnormality and mean temperature in February on Momtaz cultivar (mid flowering) during 1997, 2001-2005, and 2007 (P= 0.018).

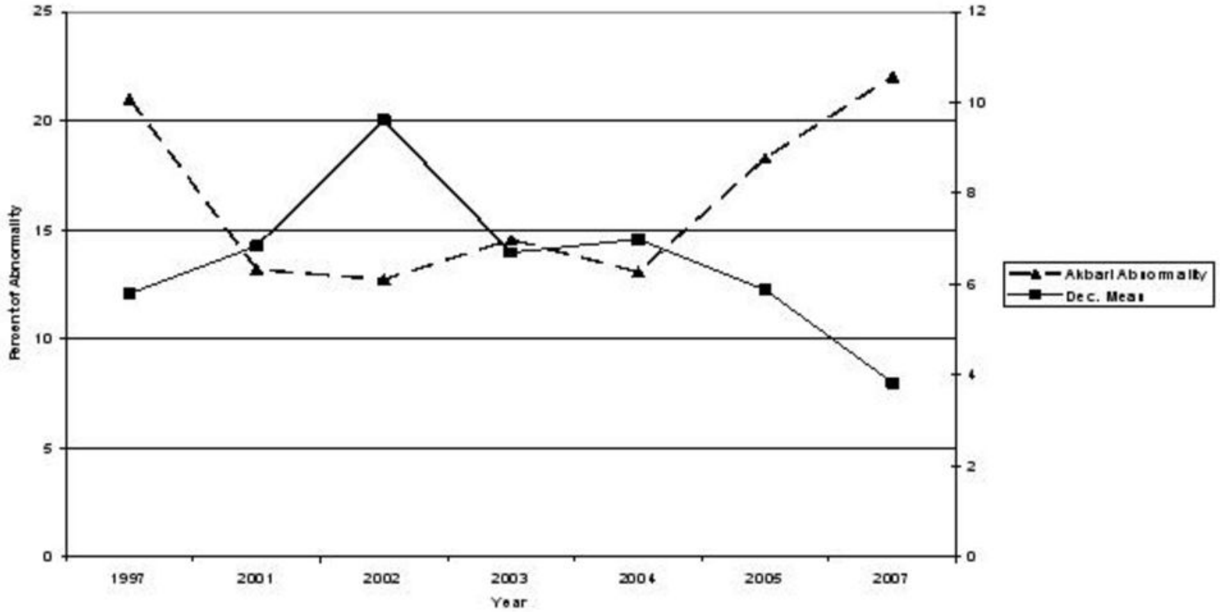

Figure 5. Negative correlation between percentages of abnormality and mean temperature in December on Akbari cultivar (late flowering) during 1997, 2001-2005, and 2007 (P= 0.012).

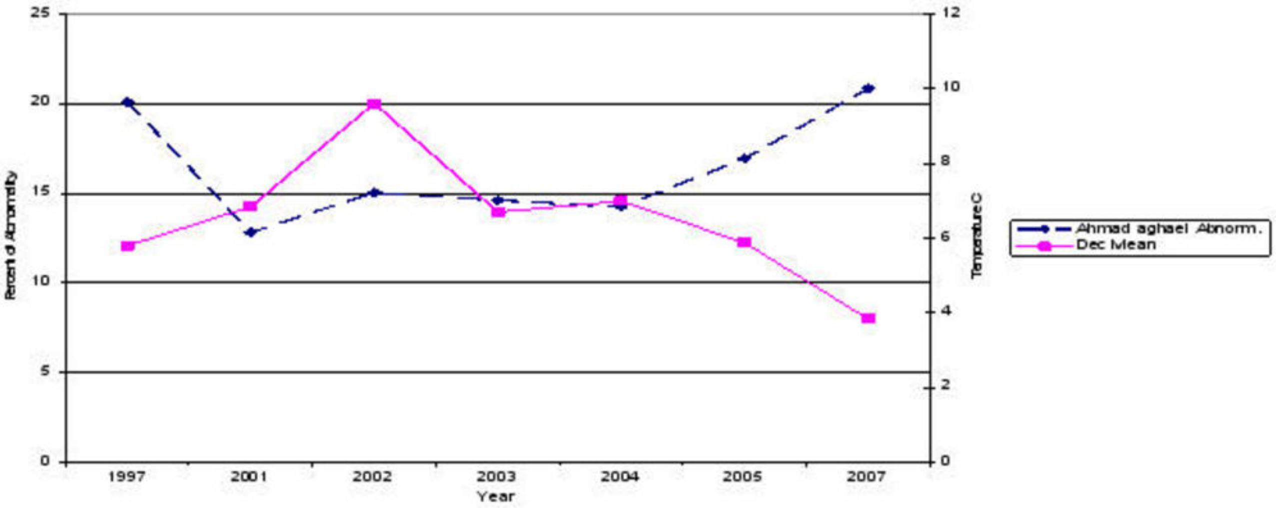

Figure 6. Negative correlation between percentages of abnormality and Mean temperature in December on Shahpasand cultivar (late flowering) during 1997, 2001-2005, and 2007 (P= 0.022).

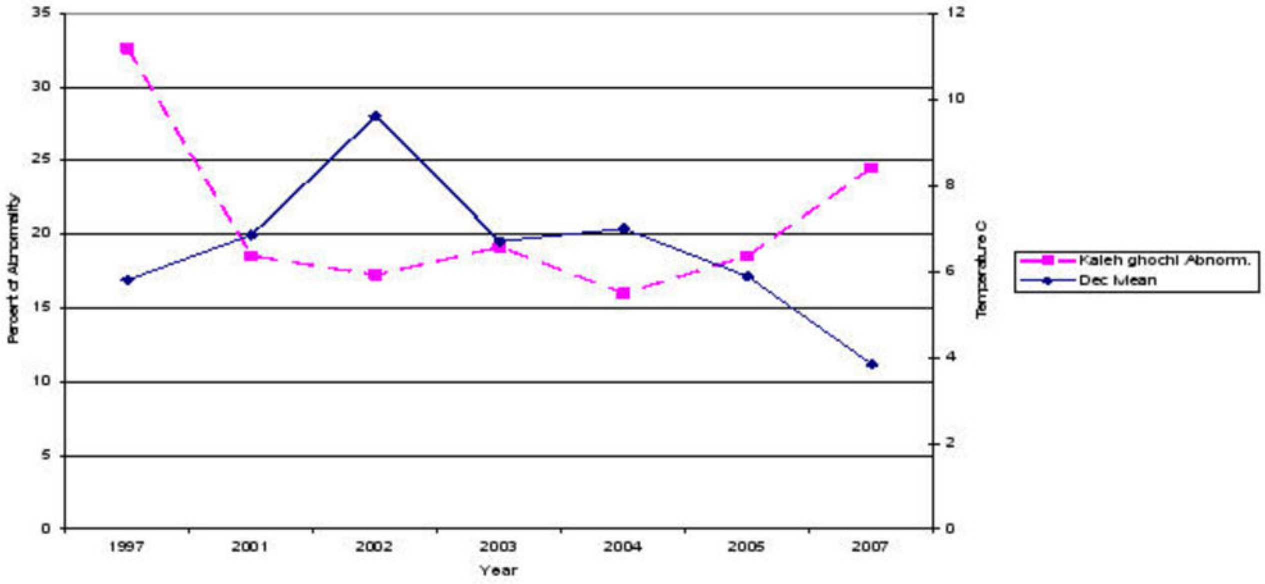

Figure 7. Negative correlation between percentages of abnormality and Mean temperature in December on Kallehghoochi cultivar (early flowering) during 1997, 2001-2005, and 2007 (P= 0.04).

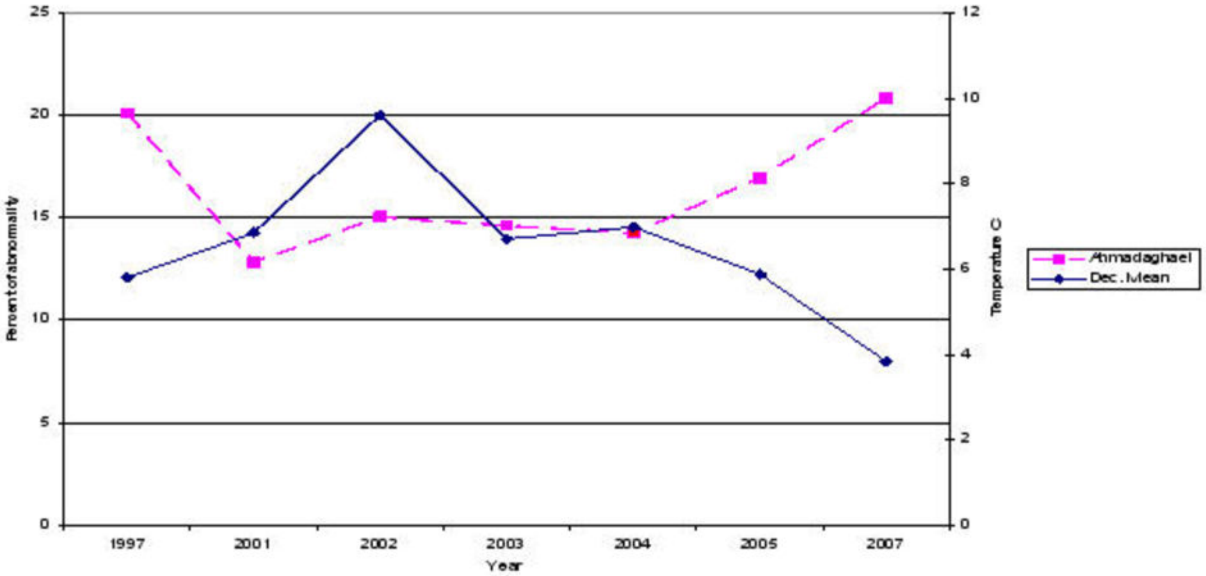

Figure 8. Negative correlation between percentages of abnormality and mean temperature in December on Ahmadaghaei cultivar (early flowering) during 1997, 2001-2005, and 2007. (P= 0.05).

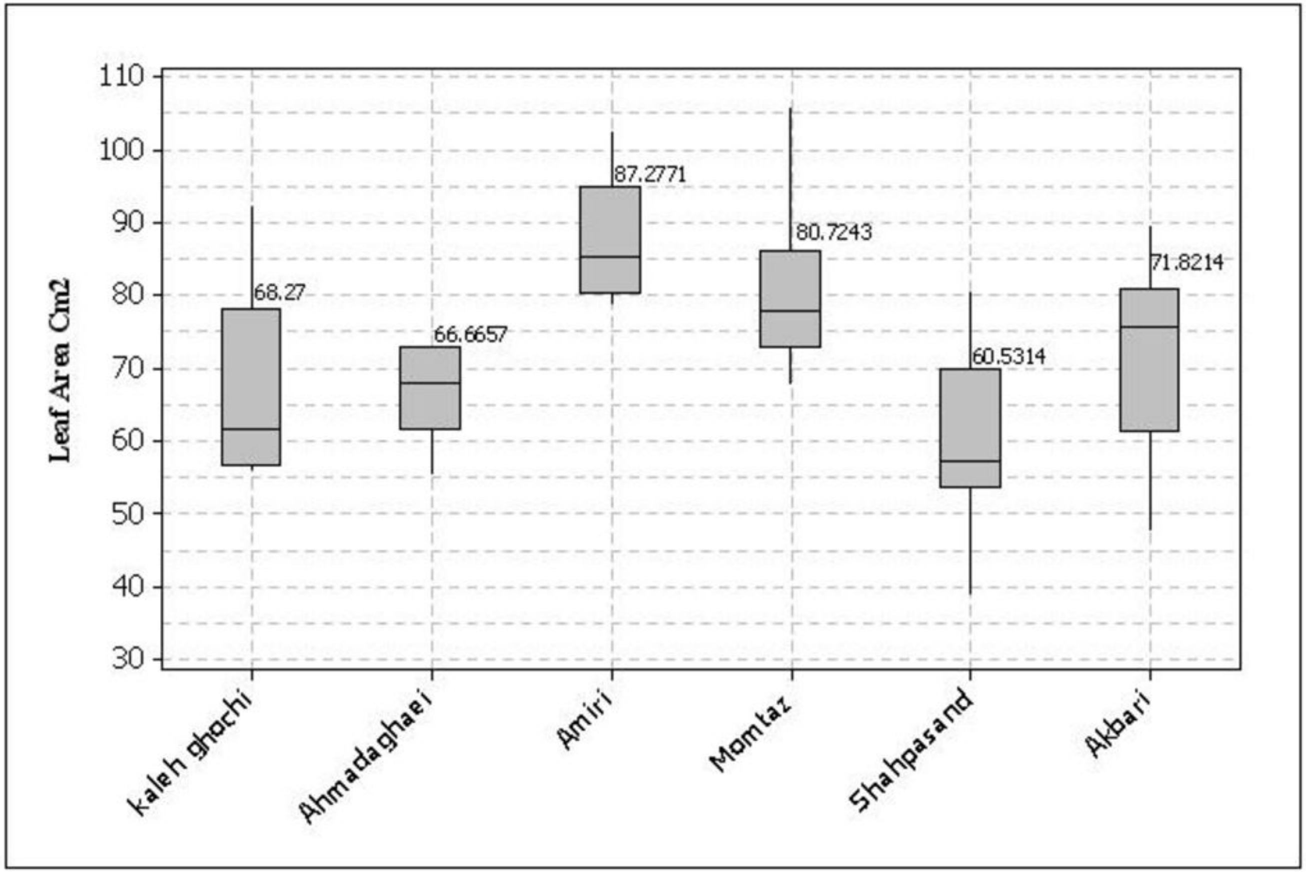

Figure 9. Leaf area box plot of kalehghochi; Ahmadaghaei; Amiri; Momtaz; Shahpasand and Akbari cultivars during 1997, 2001-2005, and 2007.