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The Influence of Seasonal Cropping on The Growth Dynamics, Dry Matter Partitioning, and Yield of Potato Cultivars in The Tropical Regions of Iran

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Abstract
Objectives: The objective of the research is to investigate the effects of high temperatures on the physiological and biochemical characteristics of different potato cultivars (Solanum tuberosum) and to assess their performance in terms of yield parameters, particularly focusing on marketable tuber yield, dry matter accumulation, and tuber bulking rate under varying climatic conditions. The study aims to identify cultivar responses to high-temperature stress and evaluate crop management practices on potato growth and development.
Data description: The study examines the performance of various potato cultivars—Coronada, Colomba, Sylvana, Challenger, Atosa, Sante, Concordia, Ottawa, Georgina, and Ribera—across autumn and winter cropping seasons in the Jiroft region of southeastern Iran. Key yield parameters, including marketable tuber yield, dry matter accumulation, and tuber allocation, were measured post-harvest, while growth parameters such as tuber bulking rate, tuber growth rate, and crop growth rate were evaluated during the growing seasons. Utilizing a split-plot design with three replicates, the research involved 60 experimental plots. Data analysis was performed using ANOVA to determine the significance of main effects and interactions. Soil samples were analyzed for nutrient status and PH before planting

Keyword: Biological Yield, Growing Season, Harvest Index, Marketable Yield, Tuber Dry Matter

1. Introduction

Potato (*Solanum tuberosum* L.), with a cultivable area of 16.49 million hectares and a production of 359 million tons, is the fourth most important crop in the world after wheat, rice, and corn. In Iran, potatoes produce approximately 47.4 million tons from 131,000 ha under cultivation (FAO, 2020). Today, potato production in the world occurs in different climates, from cold and temperate cold to subtropical and tropical regions. In Iran, potato production takes place in different climates, from cold to tropical, and in spring, summer, autumn, and winter. It is expected that, as an impact of climate change, a large part of potato production areas will be exposed to high temperatures in the coming decades (Monneveux *et al.*, 2014). The effects of climate change on potato yield are positive in temperate regions and negative in tropical and subtropical regions (Hancock *et al.*, 2014). Generally, 15-25 degrees is the best average daily temperature for potato growth (Levy 1985; Levy and Veilleux, 2007) and this plant is quite sensitive to high-temperature growth (Haverkort & Verhagen, 2008). It decreases the dry matter production in potatoes at higher temperatures (Zhou *et al.*, 2017). High temperatures are one of the most important uncontrollable factors affecting potato yield (Muthoni and Kabira, 2015; Raymundo *et al*., 2017; Singh *et al*., 2015; Trapero-Mozos *et al*., 2018). High temperatures increase respiration and decrease net photosynthesis in potatoes, resulting in reduced photosynthetic production (Hancock *et al*., 2014; Kaminski, 2014; Aien *et al*., 2011).

The effect of global warming (a temperature increase of 1.3-3.2°C) on potato production is projected to reduce the potential global potato production by 18-32% (without adaptation) and 9-18% (with adaptation) in the 2050s (Hijmans, 2003). One of the most important ways to reduce and adjust the effects of climate change on crop production is to introduce compatible cultivars and suitable planting times in each region (Hijmans *et al*., 2003). Adaptation of the crop plant to environmental conditions (which in the first place refers to the appropriate allocation of the growing season to the growing and reproductive periods) is the result of the interaction of the plant's responses to different environmental factors (such as temperature and photoperiod) (Hay and Porter, 2006). Changes in the length of the day (photoperiod), which is closely related to the cropping season in each region, have a significant impact on potato growth and development. Under short-day conditions, tuber formation started earlier, the number of tubers increased, and the growth of haulm decreased; however, the conditions of long days, tuber formation started later, stolons were longer, and haulm growth increased (Vreugdenhil *et al*., 2007). Cultivars and their compatibility with the climatic conditions of the planted area are among the most important factors influencing crop yield (Kang, 2002).

Many quantitative and qualitative traits of potatoes have been reported to be affected by cultivation area, cultivar, farm management, and other factors (Liu *et al*., 2007). The production and quality of potato tubers are influenced by several factors including the cultivar used, temperature (heat and cold), moisture stress, and nutritional factors (Levy, 1985; Levy and Veilleux, 2007; Aien *et al*., 2017). Growth analysis, the net accumulation of photosynthesis over time, has been widely used to study factors affecting plant yield and growth (Gardner *et al*., 1985). It is important to study the distribution pattern of dry matter among plant parts (Nganga, 1982). The relationship between potato yield and crop growth rate, relative growth rate, net absorption rate, leaf area index, and environmental factors was studied by (Nganga, 1982) and who showed that environmental conditions influence yield by influencing growth indices. Patil *et al*. (1990) studied the relationship between potato yield, crop growth rate, and relative growth rate, and stated that there was a close correlation between the investigated indices and yield at 70 days after planting**.**

Siadat *et al*. (1999) reported that the yield of potato cultivars is more consistent with the crop growth rate (CGR) than the tuber growth rate (TGR). Musapour Gorji and Hassanabadi (2012) studied the growth indices of potato cultivars and showed that the process of yield changes had a direct and strong correlation with tuber growth rate and tuber relative growth rate at different planting dates**.**

Ezekiel and Bhargava (1992) studied the effect of planting date on physiological growth indices and concluded that the leaf area index, crop growth rate, and total dry matter were affected by the planting date**.**

Dahmer *et al.* (2008) stated that 4-6 weeks after potato planting, owing to the rapid increase in leaves and lack of shading, the relative growth rate increases and even doubles, and then its value decreases sharply until the 12th week when the growth rate reaches up to 10%. Of course, such a thing is normal and usually occurs with an increase in the leaf area index and shading of leaves (Jonckheere *et al.*, 2004).

In another study (Borrego *et al.*, 2000) examined the growth rate and relative growth rate in different potato cultivars and stated that the highest growth rate was related to Nortena and Rast Burbank cultivars, which was 72 days after planting. The relative growth rate showed a significant increase from 90 to 108 days, and the highest value was related to the Northena, Rest Burbank, and Alpha cultivars. Sen and his colleagues (Sen *et al.*, 2014) studied the effect of planting date and plant density on potato growth indicators obtained from true seeds (TPS) and showed that the tuber bulking speed is approximately 45–60 days after planting. It increased rapidly and reached its maximum, which was probably due to the increase in the rate of photosynthesis due to the development of the leaf surface (source) and better distribution of photosynthetic materials to the tubers (reservoir) during this period of the plant. Growth and 60–75 days after transplantation. The swelling speed of the glands gradually decreased**.**

Potato cultivation in the tropical and subtropical regions of Iran is associated with many temperature challenges during autumn and winter cultivation. Therefore, in tropical regions, owing to the limitation of the growing season and the occurrence of heat and cold stresses, it is of great importance to introduce compatible potato cultivars from early to semi-early groups**.**

Potato cultivars should have special characteristics, such as early ripening, fast shedding, short dormancy period, high tuber growth rate, and high production potential for cultivation in tropical regions (Aien, 2010; Darabi, 2020).

To obtain useful information for the selection of genotypes and the most appropriate agronomic practices. In fact, potato cultivars show significant variation in growth rate owing to their genetic structure and interaction with the environment. Therefore, it is important to study the amount of dry matter produced and distributed in different plant organs during growth to determine the amount of growth and production of a cultivar. Growth analysis has been widely used to study factors affecting plant production and development, such as the accumulation of photosynthesis over time (Gardner *et al.*, 1985).

The analysis and growth of potato cultivars in different cropping in tropical regions can be a very successful help in the accurate and scientific selection of suitable and compatible potato cultivars for each cropping season, which can be the subject of this research.

2 Materials and methods

2.1 Description of the study area

The study was conducted in the Jiroft region of southeastern Iran, an area characterized by its unique climatic conditions, which include hot summers and mild winters. This city is located at 28°40′47″N 57°44′41″E and192 kilometers southeast of the Kerman Province. (Fig.1) (Open Street Map contributors 2024).

Fig 1: Geographical location of Jiroft.

The experimental site was selected based on its suitability for potato cultivation, with well-drained soils and adequate irrigation facilities. The research was carried out during the 2023-2024 growing seasons, specifically focusing on two distinct cropping seasons: autumn and winter. The average temperature and soil characteristics of the experimental site were recorded to ensure that the environmental conditions were conducive to potato growth. Figure2 (A and B), (Table 1).

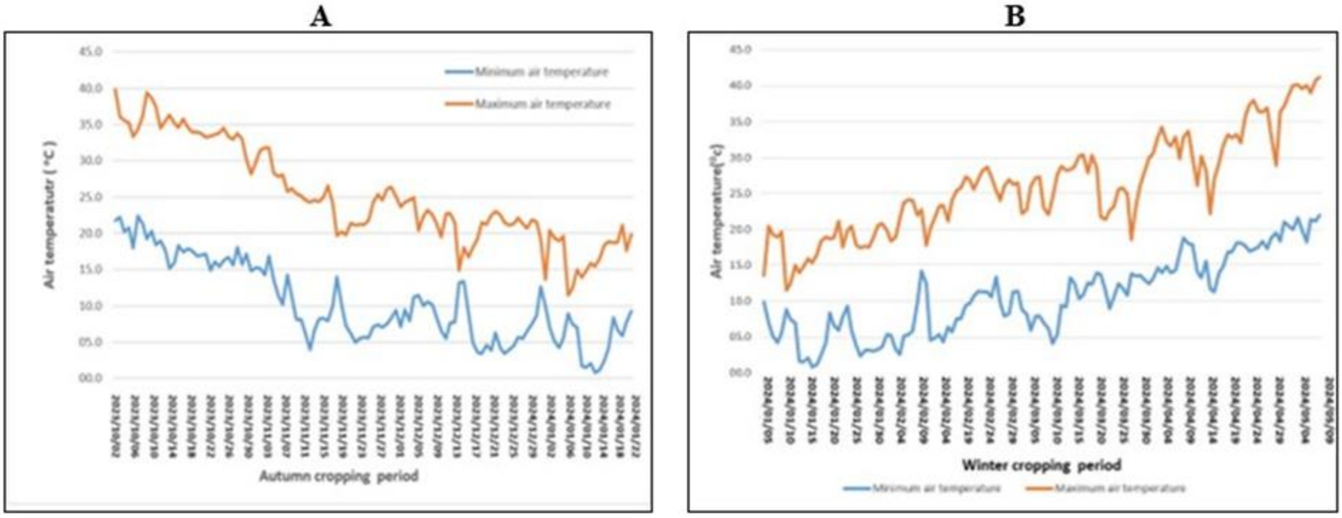

Fig 2: Daily maximum and minimum temperatures (°C) at different potato growth stages in autumn (A) and winter (B).

Table 1: Physical and chemical characteristics of experimental soil

Year	Soil texture	EC (dS m^{-1})	PH	Total N (%)	P (mg kg^{-1})	K (mg kg^{-1})
2023	Sandy loam	2.36	7.7	0.017	9.3	238
2024	Sandy loam	2.56	7.8	0.012	10..7	214

2.2 Experimental Design

A split-plot design was employed to assess the effects of different cropping seasons and potato cultivars on growth and tuber yield. The main plots were designated for the two cropping seasons (autumn and winter), while the sub-plots consisted of ten potato cultivars: Concordia, Ottawa, Georgina, Ribera, Coronada, Colomba, Sylvana, Challenger, Atossa, and Sante. The randomized complete block design (RCBD) was utilized to minimize variability and ensure the reliability of the results. Each treatment combination was replicated three times, leading to a total of 60 experimental plots (2 cropping seasons × 10 cultivars × 3 replications).

2.3 Crop Management Practices

2.3.1 Land Preparation

Before planting, the experimental plots were prepared through conventional tillage methods, which included plowing and harrowing to achieve a fine seedbed. Soil samples were collected for analysis to determine nutrient status and pH. Based on the soil test results, appropriate fertilizers were applied to ensure optimal nutrient availability for the potato plants.

2.3.2 Planting

The plant species used in the research is *Solanum tuberosum*, commonly known as potato. The identification of these species was carried out by the corresponding author who is a qualified plant taxonomist in addition to being an agricultural researcher. The method used for identification involves morphological analysis, where features such as leaf shape, flower structure, and tuber formation are examined**.**

The source of plant material was potato tubers of selected cultivars obtained from reputable local seed suppliers to ensure genetic purity and disease-free status. Planting was conducted in early September for the autumn season and late December for the winter season. The tubers were planted at a depth of approximately 10 cm and spaced 30 cm apart in rows, with a row spacing of 75 cm. The planting density was maintained at approximately 53,000 plants/ha.

2.3.3 Irrigation and Fertilization

Irrigation was managed through a drip irrigation system, which allowed for precise water application and minimized water wastage. Irrigation schedules were adjusted based on climatic conditions and soil moisture levels, ensuring that the plants received adequate water throughout the growing season.

Fertilization was performed under local agricultural practices, with a focus on N-P-K (nitrogen, phosphorus, potassium) ratios suitable for potato cultivation. A basal application of fertilizers was made at planting, followed by side-dressing at key growth stages. The total amount of fertilizers applied was calculated based on the soil nutrient analysis and the specific requirements of each cultivar.

2.3.4 Weed and Pest Management

Weed control was achieved through a combination of mechanical and chemical methods. Hand weeding was performed as necessary, and pre-emergence herbicides were applied to control weed growth effectively. Pest management strategies included regular scouting for pests and diseases, followed by the application of appropriate insecticides and fungicides when thresholds were reached.

2.3.5 Harvesting

Harvesting was carried out at physiological maturity, which was determined by the senescence of the foliage. For the autumn cropping season, harvesting occurred in late December, while for the winter season, it took place in late March. The tubers were carefully hand-harvested to minimize damage, and they were subsequently graded based on size and quality.

2.4 Data Collection

2.4.1 Growth Parameters

Several growth parameters were measured throughout the growing seasons to evaluate the effects of cropping season and cultivar on potato growth. These included:

Tuber Bulking Rate (TBR), Tuber Growth Rate (TGR), Tuber Relative Growth Rate (TRGR), Haulm Growth Rate (HGR), Crop Growth Rate (CGR) and PC (Partitioning Coefficient) were computed using the following formula**:**

$TBR = 1/GA \times (Tfw_2 - Tfw_1) / (t_2-t_1)$, (Sen *et al.*, 2014)
$TGR = 1/GA \times (Tw_2-Tw_1)/ (t_2-t_1)$ (Manrique, 1989)
$TRGR = (\ln Tw_2 - \ln Tw_1)/ (t_2-t_1)$, (Darabi and Eftekhari, 2014)
$HGR = 1/GA \times (Hw_2-Hw_1)/ (t_2-t_1)$ (Darabi and Eftekhari, 2014)
$CGR = 1/GA \times (W_2 - W_1)/ (t_2 - t_1)$ (Gardner *et al.*, 1985)
$PC = (C_1/C_2)_{equil}$, (Darabi and Eftekhari, 2014)

Where GA indicates the ground area covered by the crop, t_2 (time 2) and t_1 (time 1), Tfw_2 and Tfw_1 are tuber fresh weight (gr) at t_2 and t_1, Tw_2 and Tw_1 are tuber dry weight (gr) at t_2 and t_1, Hw_2 and Hw_1 are haulm dry weight (gr) at t_2 and t_1, and w_2 and w_1 are crop dry weights (gr) at t_2 and t_1**.** The partition coefficient is the ratio of the concentration of a substance in one medium or phase (C_1) to that in the second phase (C_2) when the two concentrations are at equilibrium.

2.4.2 Yield Parameters

The yield parameters assessed included:

2.4.2.1 Marketable Tuber Yield: This was measured by weighing the tubers post-harvest, with tubers classified as marketable based on size and quality standards.

2.4.2.2 Dry Matter Accumulation: Samples of tubers were taken for dry matter analysis, where they were dried in an oven at 70°C until a constant weight was achieved. The percentage of dry matter was calculated based on the fresh weight of the tubers.

2.4.2.3 Tuber Allocation: The proportion of dry matter allocated to tubers versus foliage was determined by comparing the dry weight of tubers to that of the above-ground biomass.

2.5 Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using the Statistical Package for Social Sciences (SAS 9.4) software. The significance of the main effects (cropping season, cultivar) and their interactions were evaluated at a significance level of $\alpha = 0.05$. When significant differences were detected, mean separation was performed using Duncan's Multiple Range Test (DMRT). to determine which treatment means were significantly different from each other.

3 Results and Discussion

3.1 Tuber Bulking Rate

The tuber bulking rate (TBR) indicates the growth rate of potato tubers and is expressed based on the fresh weight of the tubers produced per unit of land area per day (Sen *et al.*, 2014). The Tuber bulking rate is a good criterion for comparing potato cultivars and investigating the effects of climatic, nutritional, and management conditions on the performance of potato tubers during different periods of growth and development**.**

Investigation of the rate of bulking in the studied potato cultivars showed that in the autumn cropping, the Colomba cultivar at 30, 45, and 60 days after emergence by 32.9, 104.3 and 146.3 g $m^{-2}day^{-1}$, respectively, and the Sante cultivar at 90 days after emergence by 76 g $m^{-2}day^{-1}$, had the highest TBR (Fig 2-A). But in the winter cropping, the Colomba cultivar at the stages of 30 and 45 days after emergence by 27.7 and 140.7 g $m^{-2}day^{-1}$, respectively, and the Ottawa and Challenger cultivars at the stages of 60 and 90 days after the emergence by 145.7 and 41.4 g $m^{-2}day^{-1}$, respectively, had the highest TBR (Fig 3-B).

The comparison of TBR in the investigated cultivars in the autumn cropping (Fig 3-A) and in the winter cropping (Fig 3-B) shows that the TBR in all investigated cultivars was higher in the autumn cropping, which is due to the more favorable weather conditions in the autumn cropping, especially the lower temperature and shorter days in the tubers' bulking stage compared to the winter cropping. In other words, increasing the temperature at the beginning of the tuber bulking stage in winter cropping, which is shown in Figure 1, has a negative effect on tuber size and bulkiness (Fig 3-B). Howlader and Hoque (2018) showed that the trend of TBR change in potato cultivars was very different, which is consistent with the results of the present study. Information related to the tuber bulking profile in potato cultivars can help determine the most suitable harvest time and generally manage crop harvest to achieve the maximum yield of the tuber (Howlader and Hoque, 2018). Determining the rate and trend of tuber bulking in potatoes can be very efficient and useful for managing fertilizing operations, especially the time of nitrogen application (Bohl & Lave, 2004).

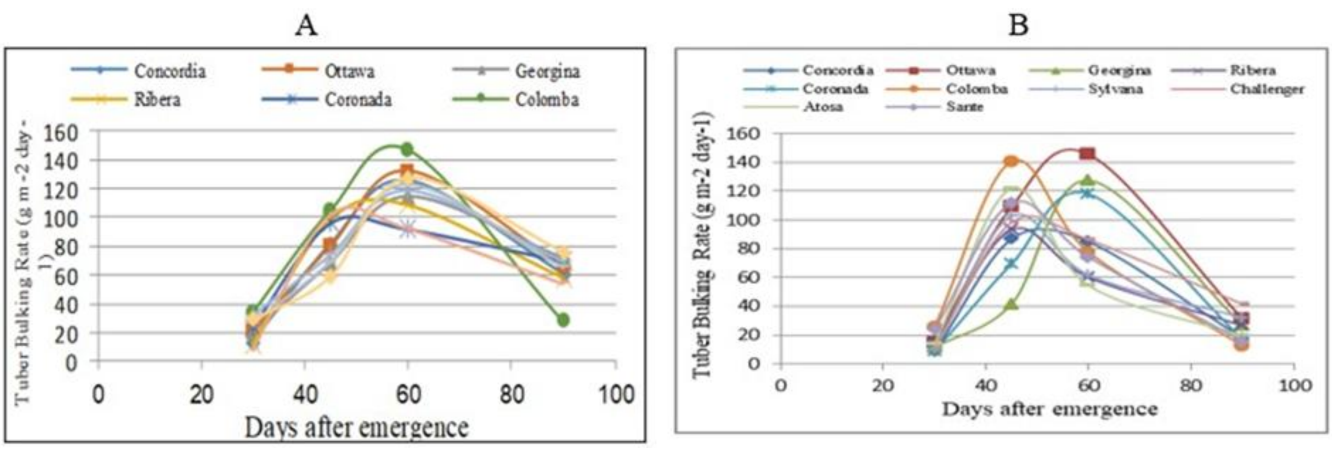

Fig 3: Tuber bulking rate (TBR) trend of potato cultivars in autumn (A) and winter (B).

3.2 Tuber Growth Rate

The tuber growth rate (TGR) indicates the rate of increase in tuber dry weight per unit time per unit of ground area. The results showed that the trend of change in the TGR of the investigated cultivars in winter cropping was completely different from that in autumn cropping. The evaluation of the TGR in autumn cropping in the studied cultivars showed that from 30 days after emergence to 45 days after emergence, the TGR of the studied cultivars were very close to each other. However, from the stage of 45 to 60 days after emergence, the difference in the TGR of cultivars became much higher, so the highest TGR in the stage of 60 days after emergence by 29.7 and 27.3 gr (tuber dry weight) m^{-2} day^{-1}, was related to Colomba and Sante cultivars, respectively (Fig A-3). In winter cropping, the highest TGR was observed at 45 days after emergence, by 24.3 and 24.2 g $m^{-2}day^{-1}$ in Colomba and Ottawa cultivars, respectively. The higher TGR in Colomba and Sante cultivars in the autumn cropping indicates that the efficiency of transferring and allocating photosynthetic matter to the tubers in the autumn cropping and in the mentioned cultivars was better than that in the other investigated cultivars (Fig 4-A). In autumn cropping, TGR decreased from 60 to 90 days after emergence in all investigated cultivars, except Georgina. The decrease in the TGR in winter cropping occurred at 45 to 60 days after emergence in all investigated cultivars except Georgina and Coronada (Fig 4-B), while the decrease in the TGR occurred later in autumn cropping. In general, the slope of tuber growth rate reduction in winter cropping in the time range of 60 to 90 days after emergence was much higher than that in autumn cropping (Fig 4-B). The reason for the decrease in the TGR in the aforementioned stages is probably the aging of the photosynthesizing organs and the decrease in the production of assimilates and the rate of their transfer to the tubers. However, the reason for the faster decrease in tuber growth in winter cropping is that the tuber bulking phase is exposed to warm conditions (the trend of temperature increase at the end of the growth and development period in winter cropping can be seen in Fig 2).

The limitation of climatic conditions (heat stress at the end of the growing season) in winter cropping caused a sharp decrease in the TGR at the tuber bulking stage (60 day after emergence) and shortened the length of the linear period of tuber growth. The tuber linear growth period in winter cropping was shorter than that in autumn cropping in all investigated cultivars except Ottawa and Sante. The short tuber growth period in the studied cultivars, especially in winter cropping, caused a decrease in the accumulation of assimilates in the tubers and, as a result, decreased tuber yield (Fig 4-A). The length of the tuber's linear growth period had a positive effect on cultivar performance. Iritani *et al*. (2003) showed that the length of the tuber's linear growth period is directly related to tuber yield. Siadat *et al.,* (2009) regarding the relationship between tuber yield and TGR stated that the increase in yield had a direct relationship with the increase in TGR and the continuation of the linear phase. Other researchers have also shown that increasing the length of the tuber linear growth period causes an increase in the accumulation of assimilates inside the tuber, and thus increases tuber yield (Iritani *et al*., 2003). A decrease in tuber growth rate in potato cultivars owing to high temperatures has been reported by (Aien *et al*., 2017). They also stated that the decrease in tuber growth rate under heat conditions (high temperatures) was greater in heat-sensitive cultivars.

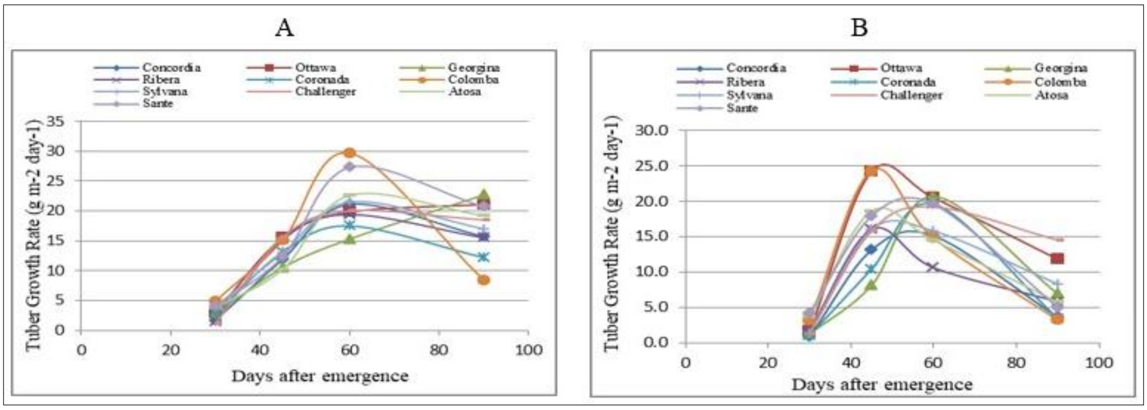

Fig 4: Tuber growth rate (TGR) trends of potato cultivars in autumn (A) and winter (B) cropping

3.3 Tuber relative growth rate

The accumulation of dry matter per unit time per unit of initial dry weight of the tuber is called the tuber relative growth rate (TRGR), which is comparable to the relative growth rate of the plant (Mousapour Gorji and Hassanabadi, 2013). The trend of changes in the TRGR of the studied cultivars in autumn and winter cropping is shown in (Fig. 5-B). The highest TRGR in autumn cropping was achieved in Colomba, Sante, and Sylvana cultivars by 0.166, 0.16, and 0.159 g/g^{-1} day^{-1}, respectively, at the first stage of sampling (30 days after emergence). In the winter cropping, the maximum TRGR (0.143 g $g^{-1}day^{-1}$) was recorded at the stage of 30 days after emergence in the Sante cultivar, which can be seen that compared to the maximum TRGR of the cultivars in the autumn cropping (0.166 g $g^{-1}day^{-1}$) (Fig 5-B). The trend of changes in the TRGR in the autumn cropping was downward in all investigated cultivars, except the Challenger and Ribera cultivars. In the Challenger and Ribera cultivars, TRGR increased up to 45 days after emergence and then decreased (Fig 5-A). In winter cropping, the changes in TRGR in Concordia, Ottawa, Challenger, Sylvana, Coronado, and Ribera cultivars showed an upward trend at the beginning (30 to 45 days after emergence) and then decreased because of the replacement of the building tissues with photosynthetic tissues. However, in the Colomba, Atossa, Sante, and Georgina cultivars, the change trend in the TRGR decreased from 30 days after emergence, although the slope of the decrease in the Georgina cultivar was much lower than that in the Sante, Atossa, and Colomba cultivars. The change in the TRGR as a result of the change in planting date was reported by Musapour Gorji and Hassanabadi (2012). Darabi and Eftekhari (2014) reported differences in TRGR trends in potato cultivars. Siadat *et al.* (2009) showed that there was a difference between cultivars in terms of the TRGR, and its rate was higher at the beginning of the growth period.

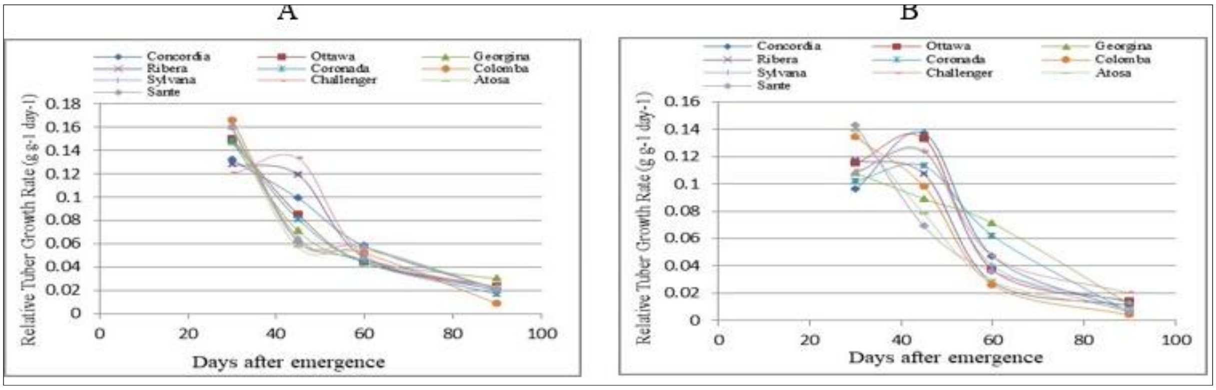

Fig. 5: Tuber relative growth rate (TRGR) of potato cultivars in autumn (A) and winter (B).

3.4 Haulm Growth Rate

Investigation of the haulm growth rate (HGR) of potato cultivars in the autumn and winter seasons showed that the HGR in these cropping seasons was completely different (Fig 6). The comparison of autumn and winter cropping charts showed that the HGR in the autumn cropping increased until 30 days after emergence and reached its maximum value and then showed a decreasing trend, while in the winter cropping in all investigated cultivars, except Georgina, increased up to 45 days after emergence and then showed a downward trend. In general, at the beginning of the growth period, in both cropping seasons, the HGR was relatively low, and with over time and the increase in the leaf area index, the rate of photosynthesis of the plant community increased, so that the slope of the curve of HGR became more intense, after which, due to the aging and shading of leaves, falling of lower leaves, and remobilization, the slope of the HGR was low and then remained almost constant**.**

The maximum HGR of the potato cultivars was much higher in winter than in autumn. The maximum HGR in the autumn cropping was 5.7 g $m^{-2}day^{-1}$, which was obtained from Concordia at 45 days after emergence (Fig 6-A), but the maximum HGR in the winter cropping was 9.3 g $m^{-2}day^{-1}$, which was obtained from Georgina at 60 days after emergence (Fig 6-B). This indicates the effect of weather conditions, especially high temperatures and long days, on the vegetative growth (haulm) of potatoes; in other words, in winter cropping, long days and high temperatures have increased the vegetative growth of potato cultivars. In winter cropping, a higher percentage of photosynthetic matter (assimilates) was transferred to the haulm, which acted as a sink. Struik *et al.* (1989) and Aien *et al*. (2017) reported an increase in potato leaf and stem growth as a result of high temperature has been reported by (Struik *et al.*, 1989 and Aien *et al.*, 2017).

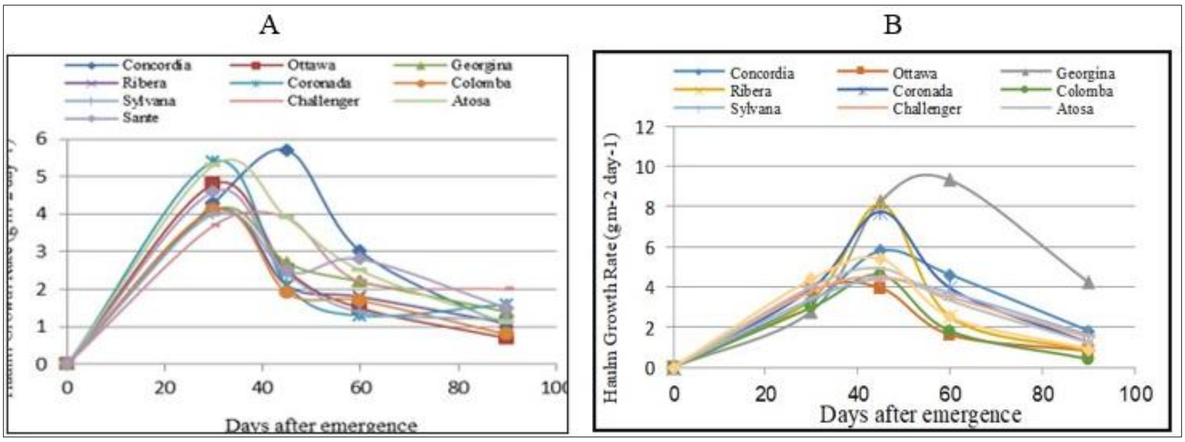

Fig 6: Haulm growth rate (HGR) of potato cultivars in autumn cropping (A) and winter cropping (B).

3.5 Crop Growth Rate

The crop growth rate (CGR) represents the amount of dry matter accumulated in plants in a specific time unit per unit of soil area. The crop growth rate in plants differs from each other and depends on genetic characteristics and environmental factors (Gardner *et al.*, 1985).

In the current study, the trend of CGR changes in autumn cropping in all investigated cultivars increased until 60 days after emergence, reached its maximum value, and then gradually decreased (Fig 7-A). In winter cropping, the CGR in Colomba, Ottawa, Sante, Ribera, Sylvana, and Atosa cultivars at 45 days after emergence, and in Georgina, Coronada, Challenger, and Concordia cultivars at 60 days after emergence reached its peak and then decreased (Fig 6-B). The gradient reduction of CGR was lower in autumn cropping and higher in winter cropping (Fig 7), which can be attributed to the heat stress at the end of the growing season in winter cropping. Research results (Aien *et al.*, 2017) showed that high temperatures significantly reduced the growth rate of potato cultivars. The observed trend in this study is consistent with the findings of Foroughian *et al.* (2018), Darabi and Iftekhari (2013), and Siadat *et al.* (2009). In the autumn cropping at the beginning of the growing season due to reasons such as high ambient temperature and soil, insufficient vegetation cover (leaf surface), and in the winter cropping due to relatively low ambient temperature and incomplete vegetation cover (leaf surface), the rate of photosynthesis and CGR was low; after some time due to the development of the plant leaf surface, the increase in the growth of the roots, and the adjustment of the ambient temperature, the photosynthesis of the plant increased, and the CGR increased rapidly and reached its maximum in the middle of the growth period. From this stage (45 to 60 days after emergence) until the end of the growth stage, the CGR decreased due to the gradual aging of the leaves and the allocation of photosynthetic matter to the tubers and skeletal tissues, resulting in a decrease in net photosynthesis.

The CGR graphs indicate that the rate of plant growth in the studied cultivars was different in each cropping season. In autumn cropping, Colomba and Sante cultivars had higher CGR values by 31 and 30.2 g $m^{-2}day^{-1}$, respectively (Fig 7-A), while in winter cropping, Georgina, Colomba, and Ottawa cultivars had higher CGR values by 30.7, 29.1 and 28.4 g $m^{-2}day^{-1}$, respectively (Fig 7-B). Midmore (2009) reported that the growth rate per unit of absorbed radiation in the potato canopy differs under the influence of different cultivars, which causes a difference in CGR.

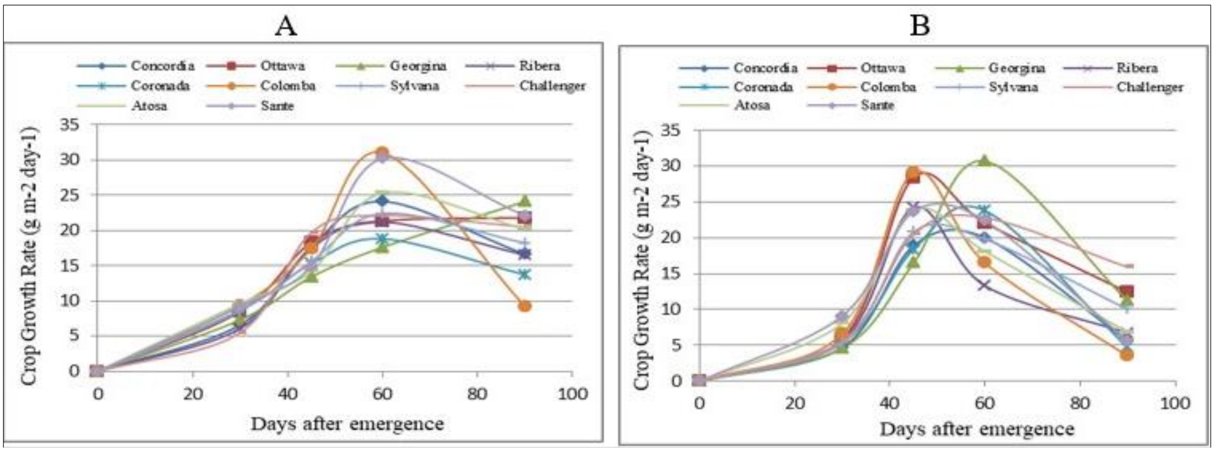

Fig. 7: Crop growth rate (CGR) trends in autumn cropping (A) and winter cropping (B).

3.6 Dry matter partitioning

3.6.1 Dry matter partitioning 60 days after emergence

Evaluation of the partitioning of assimilates and the accumulation of dry matter in different organs (tuber, roots, and haulm) of the studied cultivars in the autumn and winter cropping at 60 days after emergence (Fig.8) indicated that the percentage of allocation and accumulation of dry matter in the tuber in autumn cropping was higher than that in winter cropping. The highest and lowest percentages of dry matter accumulation in the tubers were observed in Georgina in winter cropping and Colomba in autumn cropping, respectively. The Colomba cultivar at this growth stage, with the allocation of 81.2 and 76% of dry matter to the tubers in the autumn and winter cropping, respectively, was superior to that of the other investigated cultivars, indicating that the tuber bulking stage in the Colomba cultivar was due to its early maturity. These cultivars are more suitable for areas and seasons with limited growth periods**.**

In addition, at this growth stage, in terms of the percentage of dry matter allocation to the tubers, the Sylvana and Sante cultivars in the autumn cropping and Ottawa in the winter cropping were ranked after Colomba and were superior to the other investigated cultivars (Fig 8).

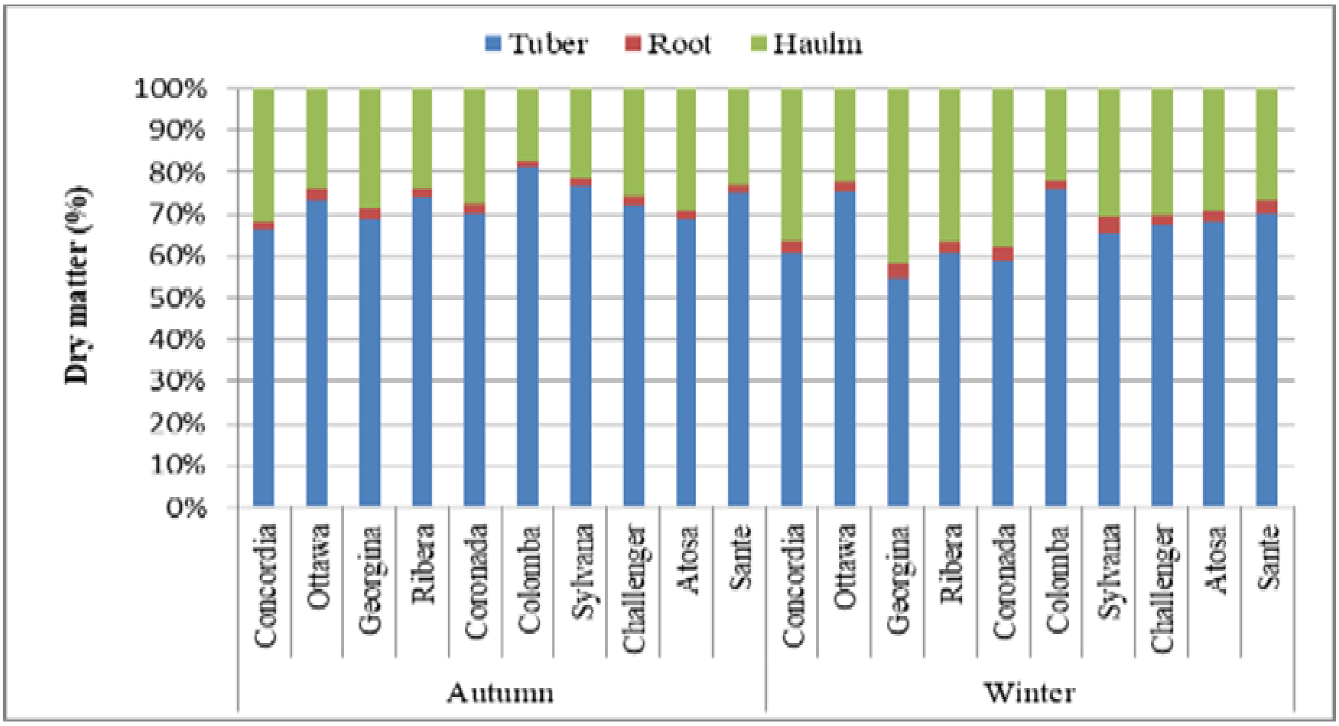

Fig 8: Partitioning of dry matter in different organs of potato cultivars in autumn and winter cropping at 60 days after emergence.

3.6.2 Dry matter partitioning 90 days after emergence (physiological maturity stage)

The amount (percentage) of dry matter partitioning among different organs (tuber, roots, and haulm) at 90 days after emergence in the studied cultivars (Fig.9) showed that the amount of dry matter allocated to tubers in autumn cropping was greater than that in winter cropping. In the autumn cropping, the main and major part of the dry matter produced (between 76.8% in the Coronada and about 83.5% in the Ottawa, Colomba, and Sylvana cultivars) was allocated to the tubers, while in the winter cropping, the allocation of dry matter to tubers was between 56.4% in Georgina and 80.1% in Ottawa. On the other hand, the amount of allocation of photosynthetic matter to shoots and, as a result, the accumulation of dry matter in haulm was higher in the winter cropping than in the autumn cropping, so the highest accumulation of dry matter in haulm by 40.5%, was related to Georgina in the winter cropping, but the amount of dry matter accumulated in the haulm of the same cultivar in the autumn cropping was recorded as 16.9%. The lowest percentage of partitioning and accumulation of dry matter in haulm was 15, 15.6 and 15.8% in the Ottawa, Colomba, and Sylvana cultivars, respectively, in the autumn cropping.

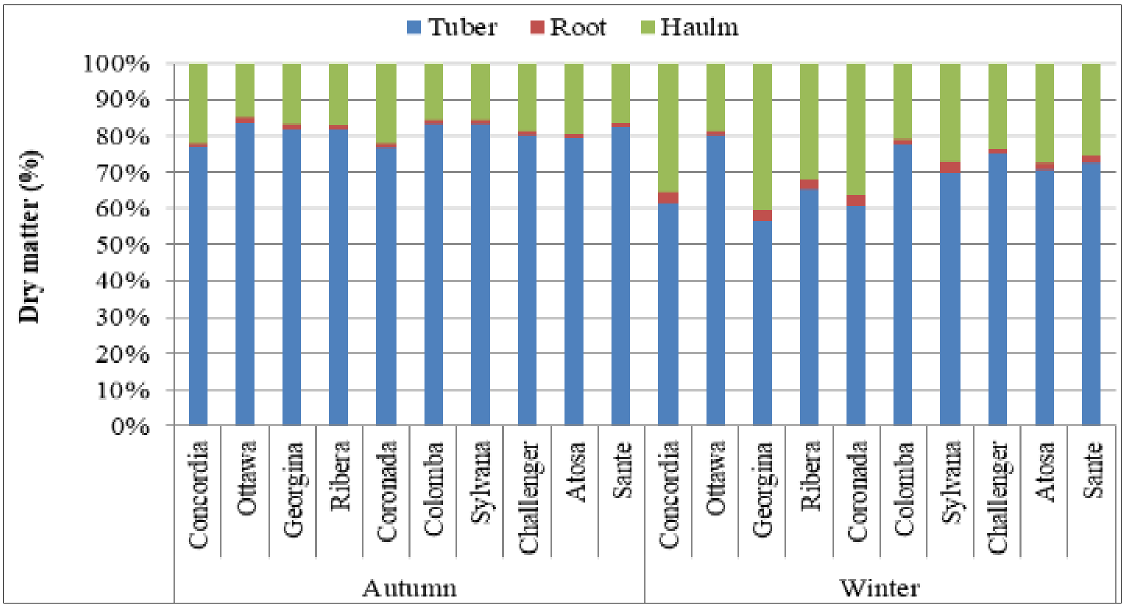

Fig 9: Partitioning of dry matter in different organs of potato cultivars in autumn and winter cropping 90 days after emergence (physiological maturity stage).

The evaluation of weather temperatures, especially the maximum daily temperature in winter cropping in the present experiment (Fig 2), indicates that the frequency of temperatures above 30 °C is higher in the stage of tuber bulking and physiological maturity. Therefore, it seems that in winter cropping, the limiting effects of high temperatures have affected the allocation of photosynthetic matter to the tubers, causing a decrease in the allocation of dry matter to the tubers and an increase in the accumulation of dry matter in the haulm of the cultivars under winter cultivation conditions. The mentioned results are consistent with the findings of some researchers, including (Shojaei *et al.*, 2019; Aien *et al.*, 2017). Heat stress in the tuber growth stage is one of the most important factors limiting potato production during winter cropping in southern Iran (Taei Samirimi *et al.*, 2017).

Potatoes need a cool climate, and the suitable temperature for it in the vegetative growth stage is 20-25°C, for photosynthesis at 16-25°C and for tuberization at 20°C (Levy, 1985; Levy and Veilleux, 2007). Temperature has a significant effect on the distribution of assimilates in different organs of potato plants. High temperatures (heat stress) reduce the partitioning of assimilates to the tuber and increase their movement towards the shoots (Lafta and Lorenzen 1995; Wolf *et al.*, 1991; Lizana *et al.*, 2017; Levy and Veilleux, 2007; Aien *et al.*, 2017). Temperatures above 23 °C have been reported to cause more allocation of dry matter to foliage (haulm) and a decrease in tuber growth (Jenkins & Mahmood, 2003). The sensitivity of different cultivars to high temperatures is different, and reports indicate that at high temperatures (up to 36°C), not only does the absorption and assimilation of CO_2 decrease by 4 to 27%, but the transfer of sugar produced in the leaves to the sinks (tubers) also decreases. The decrease in different cultivars is due to the difference in the size of the phloem vessels and, as a result, their ability to load and transport assimilates (Paul *et al.*, 2017).

3.7 Yield and yield components

3.7.1 Marketable tube weight per plant

The comparison of the interaction effect of cropping season and cultivar showed that the reaction of the investigated cultivars to the cropping season was different. The tuber weight in winter cropping compared to autumn cropping was reduced in all investigated cultivars, except for Ottawa. Therefore, the most marketable tuber weight per plant was obtained from Colomba in the autumn cropping and Ottawa in the winter cropping, by 734 and 698 g plant^{-1}, respectively, and the lowest marketable tuber weight per plant was obtained from the Ribera and Coronada cultivars in winter cropping (Table 2). The decrease in the weight of marketable tubers in the plant during winter cropping is probably due to the encounter with the tuber bulking phase at high temperatures (Fig.2). In addition to affecting tuber yield, high temperatures can change the number and weight ratio of marketable and non-marketable tubers, thus affecting the marketability of the product (Kim *et al.*, 2017; Fleischer *et al.*, 2017). The response of cultivars to environmental conditions (especially high temperatures) has been reported by some scientists (Aien *et al.*, 2017), these researchers showed that the evaluated temperature caused a significant decrease in the weight of potato cultivars.

3.7.2 Number of marketable tubers per plant

The comparison of the interaction effects of cropping season and cultivar indicated that Ribera in both crop seasons along Sante, Concordia, and Georgina cultivars in the autumn cropping had the highest number of marketable tubers per plant. More favorable conditions during the period of tuberization in the autumn cropping season (Fig.2) increased the number of marketable tubers per plant in the cultivars. The number of tubers per plant depends on the cultivar, number of stems per plant, and environmental conditions in the tuberization stage (beginning of the growing season) (Mihovilovich *et al.*, 2009). In the present study, the number of tubers per plant was affected by the cultivar and season of cultivation (environmental conditions), which is consistent with reports by Mihovilovich *et al.*, (2009) and Darabi (2007).

3.7.3 Marketable tuber yields

The comparison of marketable tuber yield (Table 2) shows the different responses of the studied cultivars to the cropping seasons and the effect of the cropping seasons on the studied cultivars. The highest marketable tuber yield was obtained from Ottawa in winter and autumn cropping (4610 and 4419 g m^{-2}) along with Colomba and Sante cultivars in autumn cropping (4423 and 4294 g m^{-2}) respectively. These results revealed the adaptability of Colomba and Ottawa cultivars to both autumn and winter cropping, and the Sante cultivar to autumn cropping in the tropical regions of southern Iran. It seems that the significant difference between the studied cultivars in terms of marketable tuber yield is due to the difference in the genetic characteristics of the cultivars and the effect of the cropping season (different weather conditions of autumn and winter cropping). The findings of other studies also show that management operations, such as compatible cultivars for each region, planting date, environmental factors, and soil fertility, play a special role in light absorption and photosynthesis, which ultimately affect tuber yield (Zrust & Geple, 2002; Rosati *et al.*, 2004; Darabi & Salehi, 2015; Mousapour Gorji & Hassanabadi, 2012). Similarly, (Hosseinpanahi *et al.*, 2010) reported that at temperatures above 20 °C, with each degree of temperature, the efficiency of nutrients and light decreases.

Table 2: Interaction effects of cropping season and cultivar on marketable yield and yield components of potato cultivars

Cropping season	Cultivar	Marketable tuber No. per plant	Marketable tuber weight (g $plant^{-1}$)	Marketable yield (g m^{-2})
	Concordia	5.8^{ef}	627^{c-e}	4118^{b-d}
	Ottawa	5.7^{eg}	672^{bc}	*4419^{ab}*
	Georgina	7.3^{a-c}	595^{e-g}	3927^{d-g}
	Ribera	7.8^{a}	626^{c-e}	4167^{b-d}
	Coronada	7.7^{ab}	647^{cd}	4275^{bc}
Autumn	Colomba	5.7^{e-g}	734^{a}	4423^{ab}
	Sylvana	6.5^{c-e}	608^{d-f}	4005^{c-f}
	Challenger	6.5^{c-e}	666^{bc}	4097^{b-e}
	Atosa	5.6^{e-g}	655^{b-d}	4271^{bc}
	Sante	7.7^{ab}	648^{cd}	4294^{a-c}
	Concordia	4.8^{g}	508^{ij}	3341^{ij}
	Ottawa	6^{d-f}	698^{ab}	4610^{a}
	Georgina	6^{d-f}	545^{hi}	3603^{hi}
	Ribera	7.8^{a}	484^{j}	3184^{j}
	Coronada	6.8^{b-d}	489^{j}	3203^{j}
Winter	Colomba	6^{d-f}	644^{c-e}	4236^{b-d}
	Sylvana	5.2^{fg}	560^{f-h}	3707^{f-h}
	Challenger	6.2^{de}	605^{d-f}	4011^{c-f}
	Atosa	5.8^{ef}	554^{g-i}	3653^{gh}
	Sante	6.2^{de}	570^{f-h}	3774^{e-h}

*Means followed by the same letters in each column are not significantly different at 5% probability level according to Duncan's Multiple Range test.

4. Conclusion

Considering the climatic changes and their consequences, including the occurrence of heat stress in winter cropping and the increase in the probability of frost and cold stress in the autumn cropping of potatoes in tropical regions of Iran, it seems that one of the most important solutions to adjust and mitigate the impact of climate change in the mentioned cropping seasons is to analyze the growth stages and yield of potato cultivars in each cropping season and introducing compatible and high potential cultivars for each cropping season. Quantitative analysis of growth and investigation of plant growth indices can be useful in the analysis of performance and the factors affecting it (Gardner *et al.*, 1985). Environmental conditions (season and planting time) can affect potato tuber yield by affecting growth indices including CGR, HGR, TRGR, TGR, TBR, and RGR (Jenkins & Mahmood, 2003; Aien *et al.*, 2017; Lizana *et al.*, 2017; Midmore, 2009; Dammer *et al.*, 2008; Foroghian *et al.*, 2019).

In this study, the TBR, TGR, TRGR, HGR, CGR, dry matter partitioning, and tuber yield of potato cultivars were affected by the cropping season. The indices of TBR, TGR, TRGR, and CGR, which are directly related to tuber yield, were superior in autumn cropping than in winter cropping due to more favorable weather conditions. The HGR index of the studied cultivars in winter cropping was higher than that in autumn cropping because of the high temperatures at the end of the growing season (Fig.2). Therefore, considering the limitations of the growth and development period of potatoes in autumn and winter cropping due to climate change and considering the trend of growth indices, especially the TBR, TGR, and the amount of marketable tuber production, Colomba, Ottawa, and Sante cultivars (especially the Colomba cultivar) are recommended as suitable cultivars for autumn cropping in tropical regions. However, in winter cropping, the Ottawa and Colomba cultivars were superior to other cultivars in terms of marketable tuber yield and growth indices, and they are recommended for winter cropping in tropical regions and similar climates.

5. Limitations

The study has several limitations that should be acknowledged. Firstly, the research was conducted in specific environmental conditions, which may not be representative of all regions where potatoes are cultivated. This limits the generalizability of the findings to other climatic zones or agricultural practices. Secondly, the study focused on a limited number of potato cultivars, which may not encompass the full range of genetic diversity available in potato breeding. This could affect the applicability of the results to other cultivars that may respond differently to environmental stresses. Additionally, the research did not account for potential interactions between different environmental factors, such as soil type, pest pressures, and varying agricultural practices, which could influence the growth and yield of potatoes. Furthermore, the study's reliance on specific statistical methods may not capture all the complexities of genotype-environment interactions, potentially oversimplifying the results. Lastly, the absence of long-term data limits the understanding of the sustainability and resilience of the identified cultivars under changing climatic conditions.

Based on the findings of this study, it is imperative for future research to persist in analyzing the performance of various potato cultivars under shifting climatic conditions to refine recommendations further and promote sustainable potato production in tropical regions. Moreover, investigating the adaptability of additional cultivars to both cropping seasons may yield a broader array of options for farmers contending with climate variability. Such comprehensive analyses will not only enhance current agricultural practices but also contribute to building resilience in potato cultivation amidst the challenges posed by climate change.

6. Declarations

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6.3 Author contributions

MJ: conceptualization, data curation, funding acquisition, investigation, methodology, resources and software; AA: formal analysis, project administation, supervision and writing-original draft; MSH: validation, visualization and writing- review & editing.

6.4 Competing Interests

The authors declare no competing interests

6.5 Ethics approval

Ourstudy does not require ethics approval.

6.6 Consent to participate

Not applicable

6.7 Consent to publish

The authors declare their consent to the publication of the article.

6.8 Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

6.9 Code availability

Not software application or custom code

6.10 Clinical Trial

Our study is not a clinical trial

7. References

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