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Interactive Effects of Vernalization, Photoperiod and Light Intensity on Reproductive Development of Wheat Cultivars

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Abstract: The interactive effects of vernalization, photoperiod and light intensity on the length of the apex or spike and main shoot, and the diameter of the main shoot of five different wheat (*Triticum aestivum* L.) cultivars (Çukurova-86, Atay-85, Lancer, Haymana-79 and Bezostaya-1) having different biological characters were investigated. The research was carried out in four independent experiments, which were the combinations of two different photoperiods (12 and 16 h.d^{-1}) and light intensities (200μmol m^{-2}s^{-1} and 500μmol m^{-2}s^{-1} PFD) with different vernalization periods. At the end of each photoperiod and light intensity treatment, supplementary illuminance, which was arranged to be 35% of main light regime, was applied for two hours. Vernalization treatment was applied for 0, 15, 30, 45 and 60 days at 2 ±1°C in a dark cold room at 80% humidity and also 90 days only in the short day-low light intensity experiments. In all experimens; ear emergence was completed in Çukurova-86 and Atay-85 in the control and all vernalization treatments while it was completed in Lancer, Haymana-79 and Bezostaya-1 in 30, 45 and 60 days of vernalization treatment. Since the spike development was slow in short day conditions and the required radiation was provided by high light intensity, the longest spike was obtained in the short day-high light intensity experiment. The shortest spike was obtained in the long day-high light intensity experiment. Low light intensity accelerated the transition of the apex from the vegetative to the reproductive stage through an effect probably similar to that of vernalization, only in short day conditions. The length of the main shoot increased because of a longer flower development stage in low light intensity than that in the high light intensity, independent photoperiod. The thickest diameter of all cultivars was obtained in short day-high light intensity. The length of the apex or spike, main shoot, and diameter of main shoot decreased with increasing vernalization periods in spring type cultivars, but increased in winter cultivars with increasing vernalization periods because winter cultivars were in their vegetative phase until they reached the required vernalized period. After these periods, the length of apex or spike and diameter of main shoot decreased with increasing vernalization periods.

Key Words: Wheat , vernalization, photoperiod, light intensity, length of apex or spike and main shoot , diameter of main shoot

Bazı Buğday Çeşitlerinin Reprodüktif Gelişimi Üzerine Vernalizasyon, Gün Uzunluğu ve Işık Yoğunluğunun Birlikte Etkileri

Özet: Farklı biyolojik karakterlerdeki buğday (*Triticum aestivum* L.) çeşitlerinin (Çukurova-86, Atay-85, Lancer, Haymana-79 ve Bezostaya-1) ana sap uç (apeks) veya başak ve ana sap uzunlukları ve ana sap çapı üzerine vernalizasyon, gün uzunluğu ve ışık yoğunluğunun birlikte etkileri incelenmiştir. Bu araştırrma, iki değişik gün uzunluğu (12 ve 16 saat.gün^{-1}) ve ışık yoğunluğunun (200μmol m^{-2}s^{-1} ve 500μmol m^{-2}s^{-1} Foton Akış Yoğunluğu) kombinasyonlarından oluşan dört bağımsız deneme ile farklı vernalizasyon sürelerinde gerçekleştirilmiştir. Denemelerde ışık periyodunun sonunda, ışık periodunun %35'ini oluşturacak şekilde 2 saat ilave ışık kullanılmıştır. Vernalizasyon işlemi 2±1°C'deki karanlık soğuk odada, % 80 nemde 0, 15, 30, 45 ve 60 günde, ayrıca yalnız kısa gün-düşük ışık yoğunluğunda 90 günde gerçekleştirilmiştir. Başak çıkışı; Çukurova-86 ve Atay-85'de kontrol ve tüm vernalizasyon uygulamalarında; Lancer Haymana-79 ve Bezostaya-1 'de ise 30, 45 ve 60 gün vernalizasyon uygulamalarında tamamlanmıştır. Kısa gündeki yavaş başak gelişimi ve yüksek ışık yoğunluğu karşısında gerekli ışınlanma sağlandığından, en uzun başak kısa gün-yüksek ışık yoğunluğunda, buna karşılık en kısa başak uzunluğu da uzun gün-yüksek ışık yoğunluğunda elde edilmiştir. Düşük ışık yoğunluğu yalnız kısa gün koşullarında vernalizasyona benzer bir etki ile ana sap ucunun vegetatif evreden reprodüktif evreye geçişini hızlandırmıştır. Ana sap uzunluğu, çiçek gelişim evresinin düşük ışık yoğunluğunda yüksek ışık yoğunluğuna göre daha uzun olması sonucu, gün uzunluğuna bağlı olmaksızın düşük ışık karşısında artmıştır. Tüm çeşitlerde en kalın ana sap çapı, kısa gün-yüksek ışık yoğunluğunda elde edilmiştir. Yazlık çeşitlerde ana sap uç veya başak uzunluğu ve ana sap çapı, vernalizasyon süresinin artışına bağlı olarak artarken; kışlık çeşitlerde, gereksinim duydukları vernalizasyon süresince vegetatif evrede olduklarından artmış, bu süreden sonra vernalizasyon süresinin artışına bağlı olarak azalmıştır.

Anahtar Sözcükler: Buğday, vernalizasyon, gün uzunluğu, ışık yoğunluğu, ana sap uç (apeks) veya başak uzunluğu, ana sap çapı

Introduction

Wheat, flower (inflorescence) induction and formation are controlled by temperature and photoperiod. Wheat is generally classified as a long-day plant in its photoperiodic response, since both flower initiation and anthesis are accelerated in most cultivars by exposure to long days (1). In addition, wheat types can also be classified as winter, spring and alternative (facultative) based on the vernalization requirements of these types.

Vernalization can be defined as the induction of the ability to respond to flowering stimuli by cold treatment (2). The vernalization response is important in adaptation of the plant lifecycle to the environment in which it is grown, so it can utilize the seasonal opportunities for growth and avoid adverse climatic factors (3). For example, in the winter type, vernalization delays flowering until the end of a certain cold period of winter. In the spring type, however, the ability to flower without exposure to low temperature allows plants to respond to day length stimuli that induce flowering and ensure that the plant reaches reproductive maturity before the onset of winter (4).

Although phenological development is controlled by more processes than vernalization, vernalization is agreed to be a major controlling factor in the induction of flowering. However, vernalization not only effects flowering, but also accelerates ear emergence principally by causing earlier formation of double ridges, thereby resulting in fewer leaves and tillers (5). The next growth period, however, i.e., the period from double ridges to ear emergence is not affected but by vernalization but by high temperature and photoperiodic regimes (6, 7).

As discussed above, photoperiod and temperature are the most important factors that affect the onset of flowering in wheat. Hence times to flowering in response to vernalization and photoperiod have been measured, since these factors have a major influence on flowering time, which is of crucial importance in determining the suitability of cultivars for particular regions (8). Although different types of flowering responses to vernalization and photoperiod have been reported for winter and spring wheat cultivars (8-13 and 14), little is known about the stages of development in which these two environmental factors, as well as the interaction between them, exert their influences on flowering. The effects of light quality on late flowering mutants of *Arabidopsis thaliana* have been investigated by Martinez-Zapater and Somerville (15). In these researches, it has been observed that vernalization, photoperiod and light quality affected flowering time. The results of experiments carried out by Friend (16) and Aspinal and Paleg (17) have also shown that an increase in light intensity and photoperiod accelerated ear emergence.

Although the individual effects of vernalization, photoperiod and light quality or the interactive effects of vernalization-photoperiod and vernalization-light quality on flowering time have been investigated, the interactive effects of vernalization-photoperiod-light intensity have not yet been investigated. Therefore, the aim of this study was to determine the combined effects of vernalization, photoperiod and light intensity on the development of apex or spike, the length of apex or spike and main shoot, the diameter of the main shoot and flowering time in some wheat cultivars of different biological characters.

Materials and Methods

In this research, bread wheat (*Triticum aestivum* L.) cultivars having different biological characters and widely grown in Turkey, (spring type; Çukurova-86, and winter types; Atay-85, Lancer, Haymana-79 and Bezostaya-1) were used.

Four independent experiments were conducted in a controlled growth room at 25/20±1°C (day/night) and at 50-55% humidity within the combinations of two different photoperiods (12 and 14h.d.$^{-1}$) and light intensities [200μmolm^{-2}s^{-1} and 500μmolm^{-2}s^{-1} Photon Flux Density (PFD)] with different vernalization periods. In this research, 12 h.d.$^{-1}$ was assumed to be a short day with respect to 16 h.d.$^{-1}$, and 200μmol m^{-2}s^{-1} was assumed to be low light intensity with respect to 500μmolm^{-2}s^{-1}. In experiments of different photoperiods and light intensities, 200 or 500μmol m^{-2}s^{-} light intensity with fluorescent/incandescent ratio of 100/35 (18) was applied in the first 12 or 16 h.d.$^{-1}$ of main light regime. Since incandescent illumination applied at the end of main light regime increases the photoperiodic effects (18), an additional of 70 or 175μmol m^{-2}s^{-1} of only incandescent illumination was applied for 2 h.d.$^{-1}$.

Wheat grains with a weight of 0.05 ±0.001 g were selected and surface sterilized. After sterilization, the grains were germinated in a dark controlled cabin at 20±1°C until germination phase-I (19), and then were vernalized at 2±1°C and > 80% humidity in a dark cold room. Vernalization treatment was applied for periods of 0 (control), 15, 30, 45 and 60 days in all experiments and also for 90 days in the short day-low light intensity experiment. The experimental schedules were so arranged that all vernalization treatments were completed simultaneously and the seedlings were transplanted to pots on the same day. Each pot contained 3150 g of soil/sand/farmyard manure ratio of 4/3/2 and held 15 plants, which were irrigated in field capacity.

The experiments were laid out in a factorial design with three replicates in the growth room and three plants were sampled from each pot in successive sampling dates, which were 15-20; 30-35; 45-50; 65-70 and 80-85 days after transplantion. Development stages of apex or spike were determined by using the method proposed by Kirby and Appleyard (20). The length of main shoot apex or spike (from the base to the top of the primordium or rachis) and the length of the main shoot (from the base of the main shoot to the top the peduncle for the eared plants) and the diameter of main shoot (the diameter of the cross-section at 1.5 cm above of the second node from the top of the plant) were measured by microocular or millimetric ruler. Moreover, the number of days from transplanting to ear emergence and the amount of total radiation (Total radiation = Photoperiod x Light intensity) were also noted down in all experiments.

The statistical analysis of measurements such as the length of the apex or spike and main shoot and diameter of main shoot were performed with SPSS for Windows and the differences among the means were compared with LSD (Least Significant Differences) at a 5% significant level.

Results and Discussion

a) Effects of vernalization, photoperiod and light intensity on the length and development of the apex or spike

Development stages and the changes in the length of the main shoot apex or spike of the wheat cultivars were investigated in different photoperiod and light intensity experiments for different sampling times, as well as for control and vernalization treatments. Development of plants (i.e., ear emergence) was completed in 80-85 days in the all experiments except the long day-high light intensity experiment (Tables 1, 2, 3 and 4). The ear emergence in the long day-high light intensity experiment was completed in 65-70 days due to rapid development of plants. Vernalization requirements of the cultivars used in this research were determined according to the vernalization period in which the longest spike was obtained after developments of plants were completed (Figs 1 a, b, c and d). The vernalization requirement of Lancer, Haymana-79 and Bezostaya-1 were determined as 30, 45, and 30 days respectively. Therefore, these cultivars were classified as winter type cultivars. However, Atay-85 which has been certified as a winter type by the Turkish Seed Certification Center, this cultivar (like the spring type Çukurova-86), did not show vernalization requirement in all experiments.

In all experiments, switching on the apex to reproductive stage (double-ridge) in the control (no vernalization) was observed in 30-35 days sampling time for Çukurova-86, and 45-50 days for Atay-85 (Tables 1, 2, 3 and 4). Although ear emergence of both Çukurova-86 and Atay-85 was observed in control and in all vernalization treatments, their spike lengths decreased with increasing vernalization period (Figs 1a, b, c and d). The decrease in spike length started from the control (0 day) in Çukurova-86 but from 15 days of vernalization in Atay-85. Vernalization treatments accelerated switching on the apex to reproductive stage and caused early ear emergence, thereby decreasing the spike length significantly (Table 5, Figs 1a, b, c, d). Therefore, it can be concluded that excessive vernalization led to substantial decrease in spike length. Similar results have also been reported by (5, 10).

Evans (21) reported that flower initiation was fastest in short day conditions ($<14\text{h.d}^{-1}$) but flower development was fastest in long day conditions. In this research, similar flower initiation and development behaviors were also observed in short day-low light intensity conditions in control and vernalization treatments (Table 1 and 2). This was attributed to faster transition from the vegetative to the reproductive stage (accelerating flower initiation) in low light intensity, probably through an effect similar to that of vernalization (Table 1 and 2). This effect also caused the formation of fewer leaves in the short day-low light intensity experiment (22). However, in the short day experiment, ear emergence was retarded in low light intensity compared to high light intensity due to slower flower development. This retarding effect in the control was not significant for Çukurova-86 (1 day) but for Atay-85 (13 days) (Table 5). Therefore, the longest spike was determined in short day-high light intensity experiment. This was probably attributed to longer duration of flower development stage in short day and the required radiation provided by high light intensity (Figs 1a, b, c, d) .

In the long day experiment, early ear emergence of 12 days in Çukurova-86 and of 8 days in Atay-85 in the control were obtained in high light intensity. The timing of the change in the apex from the vegetative stage to the reproductive stage depends on genetically determined

Table 1. Effects of vernalization periods on apex or spike development of main shoot in wheat cultivars under short day-low light intensity conditions (Apex or spike development stages^{+} were studied in 9 plants and the number of plants).

		Days From Transplanting to Sampling Time (day)												
		15-20		30-35		45-50			65-70			80-85		
Cultivars	Vernalization Periods (day)	Vegetative Stage	Spike Development Stage	Vegative Stage	Spike Development Stage	Vegetative Stage	Spike Development Stage	Ear Emergence Stage	Vegetative Stage	Spike Development Stage	Ear Emergence Stage	Vegetative Stage	Spike Development Stage	Ear Emergence Stage
Çukurova-86	0 (Control)	A(9)	0	0	C(9)	0	G(9)	0	0	0	9	0	0	9
	15	A(9)	0	0	G(9)	0	I(9)	0	0	0	9	0	0	9
	30	B(3)	C(6)	0	I(9)	0	I(9)	0	0	0	9	0	0	9
	45	B(3)	C(6)	0	I(9)	0	I(4)	5	0	0	9	0	0	9
	60	0	D(9)	0	I(9)	0	0	9	0	0	9	0	0	9
	90	0	F(9)	0	I(9)	0	0	9	0	0	9	0	0	9
Atay-85	0 (Control)	A(9)	0	B(9)	0	B(3)	C(6)	0	0	E(9)	0	0	I(6)	3
	15	A(9)	0	0	E(9)	0	G(9)	0	0	I(9)	0	0	0	9
	30	A(8)	0	0	F(9)	0	I(9)	0	0	0	9	0	0	9
	45	B(3)	C(6)	0	G(9)	0	I(9)	0	0	0	9	0	0	9
	60	B(3)	C(6)	0	H(9)	0	I(9)	0	0	0	9	0	0	9
	90	0	C(9)	0	I(9)	0	I(9)	0	0	0	9	0	0	9
Lancer	0 (Control)	A(9)	0	A(9)	0	A(9)	0	0	A(9)	0	0	B(9)	0	0
	15	A(9)	0	A(9)	0	B(9)	0	0	A(9)	0	0	B(9)	0	0
	30	A(9)	0	B(6)	C(3)	B(1)	D(8)	0	0	I(9)	0	0	0	9
	45	B(9)	0	0	C(9)	0	G(9)	0	0	0	9	0	0	9
	60	B(3)	C(6)	0	G(9)	0	I(9)	0	0	0	9	0	0	9
	90	B(3)	C(6)	0	H(9)	0	I(9)	0	0	0	9	0	0	9
Haymana-79	0 (Control)	A(9)	0	A(9)	0	A(9)	0	0	A(9)	0	0	B(9)	0	0
	15	A(9)	0	A(9)	0	A(9)	0	0	B(9)	0	0	B(9)	0	0
	30	A(9)	0	A(9)	0	A(1)	C(8)	0	0	I(9)	0	0	0	9
	45	A(9)	0	0	C(9)	0	G(9)	0	0	I(5)	4	0	0	9
	60	0	C(9)	0	H(9)	0	I(9)	0	0	0	9	0	0	9
	90	0	C(9)	0	I(9)	0	I(9)	0	0	0	9	0	0	9
Bezostaya-1	0 (Control)	A(9)	0	B(9)	0	A(9)	0	0	A(9)	0	0	B(9)	0	0
	15	A(9)	0	B(9)	0	B(9)	0	0	B(9)	0	0	0	C(9)	0
	30	B(9)	0	B(5)	C(4)	0	G(9)	0	0	I(9)	0	0	0	9
	45	0	C(9)	0	H(9)	0	I(9)	0	0	0	9	0	0	9
	60	0	C(9)	0	H(9)	0	I(9)	0	0	0	9	0	0	9
	90	0	D(9)	0	I(9)	0	I(9)	0	0	0	9	0	0	9

(+) Apex or spike development stages: (A; B) vegetative, (C) double-ridge, (D) glume primordium, (E) lemma primordium, (F) floret primordium, (G) spikelet development, (H) terminal spikelet, (I) spike development (Kirby and Appleyard, 1984).

responses to photoperiod and vernalization (23). Ear emergence in spring wheat cultivars was accelerated with the increase of the photoperiod duration from short day to long day (9). The results showed that the rate of reproductive development increased in long day, but faster reproductive development was also observed in long day-high light intensity. Unlike the short day experiment, the hastening effect (faster transition from the vegetative to reproductive stage) in low light intensity, similar to vernalization, disappeared in long day conditions. This revealed that the hastening effect of low light intensity could only be observed in short day conditions.

On the other hand, in both light intensity conditions the transition to the reproductive stage in long day experiments was faster than that of short day experiments (Tables 1, 2, 3, 4 and 5). and this rapid transition resulted in shorter spikes (Figs 1a, b, c, d). In this research, in both photoperiodic regimes, ear emergence was observed with lower amounts of total radiation in low light intensity than in high light intensity (Table 5). It is probable that, low light intensity, like vernalization, decreased the required total radiation for transition to reproductive stage.

Since winter cultivars Lancer, Haymana-79 and Bezostaya-1 were in vegetative stage and did not pass to reproductive stage throughout the experimental time in control and 15 days vernalization, ear emergence was not completed until the last sampling day (Tables 1, 2, 3 and 4; Fig. 1). In vernalization treatment of 30 days, switching on the apex from vegetative to reproductive stage was completed (in 40-45 days sampling time) for

Table 2. Effects of vernalization periods on apex or spike development of main shoot in wheat cultivars under short day-high light intensity conditions (Apex or spike development stages^{+} were studied in 9 plants and the number of plants).

		Days From Transplanting to Sampling Time (day)												
		15-20		30-35		45-50			65-70			80-85		
Cultivars	Vernalization Periods (day)	Vegetative Stage	Spike Development Stage	Vegative Stage	Spike Development Stage	Vegetative Stage	Spike Development Stage	Ear Emergence Stage	Vegetative Stage	Spike Development Stage	Ear Emergence Stage	Vegetative Stage	Spike Development Stage	Ear Emergence Stage
Çukurova-86	0 (Control)	A(9)	0	0	C(9)	0	I(9)	0	0	0	9	0	0	9
	15	A(9)	0	0	F(9)	0	I(9)	0	0	0	9	0	0	9
	30	B(9)	0	0	I(9)	0	I(5)	4	0	0	9	0	0	9
	45	B(1)	C(8)	0	I(9)	0	I(1)	8	0	0	9	0	0	9
	60	0	E(9)	0	I(9)	0	0	9	0	0	9	0	0	9
Atay-85	0 (Control)	A(9)	0	B(7)	C(2)	0	D(9)	0	0	I(9)	0	0	0	9
	15	A(9)	0	0	D(9)	0	I(9)	0	0	I(6)	3	0	0	9
	30	A(9)	0	0	F(9)	0	I(9)	0	0	0	9	0	0	9
	45	B(9)	0	0	G(9)	0	I(9)	0	0	0	9	0	0	9
	60	0	D(9)	0	H(9)	0	I(9)	0	0	0	9	0	0	9
Lancer	0 (Control)	A(9)	0	A(9)	0	A(9)	0	0	A(9)	0	0	B(9)	0	0
	15	A(9)	0	A(9)	0	B(9)	0	0	B(9)	0	0	B(9)	0	0
	30	A(9)	0	A(9)	0	0	C(9)	0	0	H(9)	0	0	I(5)	4
	45	A(9)	0	B(1)	C(8)	0	G(9)	0	0	I(3)	6	0	0	9
	60	B(8)	C(1)	0	F(9)	0	I(9)	0	0	0	9	0	0	9
Haymana-79	0 (Control)	A(9)	0	A(9)	0	A(9)	0	0	A(9)	0	0	B(9)	0	0
	15	A(9)	0	A(9)	0	B(9)	0	0	B(9)	I(0)	0	B(9)	0	0
	30	A(9)	0	B(9)	0	0	E(9)	0	0	I(9)	0	0	0	9
	45	A(9)	0	B(5)	C(4)	0	G(9)	0	0	I(2)	7	0	0	9
	60	A(9)	0	0	F(9)	0	I(9)	0	0	0	9	0	0	9
Bezostaya-1	0 (Control)	A(9)	0	A(9)	0	B(9)	0	0	B(9)	0	0	B(9)	0	0
	15	A(9)	0	A(9)	0	B(9)	0	0	B(6)	C(3)	0	0	D(9)	0
	30	A(9)	0	B(8)	C(1)	0	E(9)	0	0	I(9)	0	0	0	9
	45	B(9)	0	0	D(9)	0	H(9)	0	0	I(1)	8	0	0	9
	60	B(2)	C(7)	0	I(9)	0	I(9)	0	0	0	9	0	0	9

Explanation of (+) is given in Table 1.

winter cultivars in all experiments, but for Haymana-79 and Bezostaya-1 only in long day-high light intensity (in 30-35 days sampling time). Winter cultivars have certain vernalization requirements for flowering and switching on to reproductive stage (Tables 1, 2, 3 and 4). However, the spike length of these cultivars decreased with increasing vernalization period after the required vernalization had been provided for each cultivar. Consequently, excessive vernalization caused early ear emergence due to its hastening effect from the vegetative to the reproductive stage (Figs 1a, b, c, d).

In the short day conditions, the transition rate from the vegetative to the reproductive stage is faster in low light intensity than that in high light intensity (Table 1, 2). The hastening effect of low light intensity, similar to vernalization, appeared only in short day conditions. Therefore, since the short day accelerated the transition from the vegetative to the reproductive stage and high light intensity provided the necessary radiation for spike development, the longest spikes were obtained in the short day-high light intensity experiment (Figs 1a, b). However, the shortest spike was obtained in the short day-low light intensity, since low light intensity caused early ear emergence (Table 5 and Figs 1a, b). In experiments with vernalization treatments of 30 days, ear emergence in low light intensity was observed to occur 10 days earlier in Lancer and 4 days earlier in Haymana-79 and Bezostaya-1 than that in high light intensity.

Davidson et al. (8) and Terzioglu (10) reported that long day accelerated the anthesis in completely vernalized winter cultivars but provided only vegetative development in unvernalized winter cultivars. After floral induction, long day conditions in winter cultivars accelerated the

Table 3. Effects of vernalization periods on apex or spike development of main shoot in wheat cultivars under long day-low light intensity conditions (Apex or spike development stage$^+$ were studied in 9 plants and the number of plants).

		Days From Transplanting to Sampling Time (day)												
		15-20		30-35		45-50			65-70			80-85		
Cultivars	Vernalization Periods (day)	Vegetative Stage	Spike Development Stage	Vegative Stage	Spike Development Stage	Vegetative Stage	Spike Development Stage	Ear Emergence Stage	Vegetative Stage	Spike Development Stage	Ear Emergence Stage	Vegetative Stage	Spike Development Stage	Ear Emergence Stage
Çukurova-86	0 (Control)	A(9)	0	0	F(9)	0	I(9)	0	0	0	9	0	0	9
	15	B(9)	0	0	H(9)	0	I(4)	5	0	0	9	0	0	9
	30	0	E(9)	0	I(9)	0	0	9	0	0	9	0	0	9
	45	0	F(9)	0	I(9)	0	0	9	0	0	9	0	0	9
	60	0	H(9)	0	I(9)	0	0	9	0	0	9	0	0	9
Atay-85	0 (Control)	A(9)	0	B(7)	C(2)	0	H(9)	0	0	I(2)	7	0	0	9
	15	A(9)	0	0	H(9)	0	I(9)	0	0	0	9	0	0	9
	30	B(8)	C(1)	0	H(9)	0	I(9)	0	0	0	9	0	0	9
	45	B(4)	C(5)	0	I(9)	0	I(9)	0	0	0	9	0	0	9
	60	0	D(9)	0	I(9)	0	I(4)	5	0	0	9	0	0	9
Lancer	0 (Control)	A(9)	0	A(9)	0	A(9)	0	0	B(9)	0	0	B(9)	0	0
	15	A(9)	0	A(9)	0	B(9)	0	0	B(9)	0	0	B(8)	C(1)	0
	30	A(9)	0	B(8)	C(1)	0	H(9)	0	0	I(9)	0	0	0	9
	45	B(9)	0	0	G(9)	0	I(9)	0	0	0	9	0	0	9
	60	0	F(9)	0	I(9)	0	I(1)	8	0	0	9	0	0	9
Haymana-79	0 (Control)	A(9)	0	A(9)	0	A(9)	0	0	B(9)	0	0	B(9)	0	0
	15	A(9)	0	A(9)	0	B(9)	0	0	B(9)	0	0	B(6)	C(3)	0
	30	A(9)	0	B(6)	C(3)	0	H(9)	0	0	I(3)	6	0	0	9
	45	B(9)	0	0	E(9)	0	I(9)	0	0	0	9	0	0	9
	60	0	E(9)	0	I(9)	0	I(2)	7	0	0	9	0	0	9
Bezostaya-1	0 (Control)	A(9)	0	A(9)	0	A(9)	0	0	B(9)	0	0	B(9)	0	0
	15	A(9)	0	A(9)	0	B(9)	0	0	0	C(9)	0	0	E(9)	0
	30	B(9)	0	B(5)	C(4)	0	H(9)	0	0	I(2)	7	0	0	9
	45	B(2)	C(7)	0	H(9)	0	I(9)	0	0	0	9	0	0	9
	60	0	F(9)	0	I(9)	0	0	9	0	0	9	0	0	9

Explanation of (+) is given in Table 1.

transition to reproductive stage and the rate of reproductive development. Reproductive development of winter cultivars is faster in high light intensity than in low light intensity. However, long day conditions caused early ear emergence resulting in formation of the shortest spike length (Figs 1c, d and Table 5). These results showed that the hastening effect of low light intensity, similar to vernalization, disappeared in long day conditions. In long day conditions, ear emergence was completed at 4 days in Lancer, 13 days in Haymana-79 and 11 days in Bezostaya-1 earlier in high light intensity than that in low light intensity.

The vernalization requirement of the cultivars used in this research was studied with reference to the vernalization period in which the longest spike was obtained in all experiment (Fig. 1). The ear emergence of Çukurova-86 was found to be completed in control treatments since this cultivar is spring type and did not require vernalization treatment in any of the experiments (Table 5). Although the ear emergence of Atay-85 was completed in control treatments, the longest spike was obtained after 15 days of vernalization treatment in short day-high light intensity. The length of the spike decreased with increasing vernalization period. Atay-85 was positively affected by a short period of vernalization treatment since it was considered to be an alternative type cultivar. However, Lancer, Haymana-79 and Bezostaya-1 were classified as winter types according to their response to vernalization.

In this research within the required vernalization periods, the apex or spike length of main shoot of the cultivars for different photoperiod and light intensities are plotted versus five different sampling days (Fig 2). The ear emergence of Çukurova-86 was completed in 65-

Table 4. Effects of vernalization periods on apex or spike development of main shoot in wheat cultivars under long day-high light intensity conditions (Apex or spike development stage^{+} were studied in 9 plants and the number of plants).

		Days From Transplanting to Sampling Time (day)										
		15-20		30-35			45-50			65-70		
Cultivars	Vernalization Periods (day)	Vegetative Stage	Spike Development Stage	Vegative Stage	Spike Development Stage	Ear Emergence Stage	Vegetative Stage	Spike Development Stage	Ear Emergence Stage	Vegetative Stage	Spike Development Stage	Ear Emergence Stage
Çukurova-86	0 (Control)	A(9)	0	0	G(9)	0	0	I(3)	6	0	0	9
	15	0	D(9)	0	I(9)	0	0	0	9	0	0	9
	30	0	G(9)	0	I(9)	1	0	0	9	0	0	9
	45	0	I(9)	0	0	9	0	0	9	0	0	9
	60	0	I(9)	0	0	9	0	0	9	0	0	9
Atay-85	0 (Control)	A(9)	0	B(5)	C(4)	0	0	I(9)	0	0	0	9
	15	B(9)	0	0	H(9)	0	0	0	9	0	0	9
	30	0	D(9)	0	H(9)	0	0	0	9	0	0	9
	45	0	E(9)	0	I(9)	0	0	0	9	0	0	9
	60	0	H(9)	0	I(9)	0	0	0	9	0	0	9
Lancer	0 (Control)	A(9)	0	A(9)	0	0	A(9)	0	0	B(9)	0	0
	15	A(9)	0	A(9)	0	0	A(9)	0	0	B(8)	C(1)	0
	30	A(9)	0	B(6)	C(3)	0	0	H(9)	0	0	0	9
	45	B(3)	C(6)	0	H(9)	0	0	0	9	0	0	9
	60	0	E(9)	0	I(9)	0	0	0	9	0	0	9
Haymana-79	0 (Control)	A(9)	0	A(9)	0	0	A(9)	0	0	B(9)	0	0
	15	A(9)	0	A(9)	0	0	B(9)	0	0	B(5)	C(4)	0
	30	A(9)	0	B(4)	C(5)	0	0	H(9)	0	0	0	9
	45	B(7)	C(2)	0	H(9)	0	0	I(2)	7	0	0	9
	60	0	E(9)	0	I(9)	0	0	0	9	0	0	9
Bezostaya-1	0 (Control)	A(9)	0	A(9)	0	0	A(9)	0	0	B(9)	0	0
	15	A(9)	0	A(9)	0	0	B(7)	C(2)	0	0	F(9)	0
	30	B(9)	0	B(3)	C(6)	0	0	I(9)	0	0	0	9
	45	0	E(9)	0	I(9)	0	0	0	9	0	0	9
	60	0	H(9)	0	I(9)	0	0	0	9	0	0	9

Explanation of (+) is given in Table 1.

70 days sampling time in all experiments, and Atay-85 in 80-85 days sampling time in short day conditions and 65-70 days sampling time in long day conditions. The longest spikes of Çukurova-86 and Atay-85 were obtained in short day-high light intensity with 40x10^{4} and 43.8x10^{4}day.µmol m^{-2}s^{-1} total radiation respectively. Inadequate total radiation in low light intensity in both short and long day experiments and rapid development in long day-high light intensity probably caused short spike formation (Figs 2a, b and Table 5). Although both cultivars were headed with approximately equal total radiation both in short day-high and long day-high light intensity, shorter spike length was obtained in long day-high light intensity, probably due to early ear emergence. In required vernalization treatments where the longest spike of Lancer and Bezostaya-1 (30 days of vernalization) was obtained, ear emergence of Lancer and Bezostaya-1 was completed in 65-70 days in long day and in 80-85 days in short day conditions. On the other hand, in required vernalization treatments where the longest spike of Haymana-79 (45 days of vernalization) was obtained, ear emergence was completed in 80-85 days in short day-low light intensity and in 65-70 days in the other experiments (Figs 2c, d, e). The longest spike was obtained with Lancer, Haymana-79 and Bezostaya-1 in the short day-high light intensity experiment with total radiation of 54x10^{4}, 41.9x10^{4} and 53.3x10^{4}day.µmol m^{-2}s^{-1} respectively (Figs 2c, d, e and Table 5). In winter cultivars, inadequate total radiation in low light intensity of both short and long day experiments and slower development in long day-low light intensity caused short spike formation. Although the length of spikes of Haymana-79 obtained in short day-low and high light intensity were almost equal, total radiation was

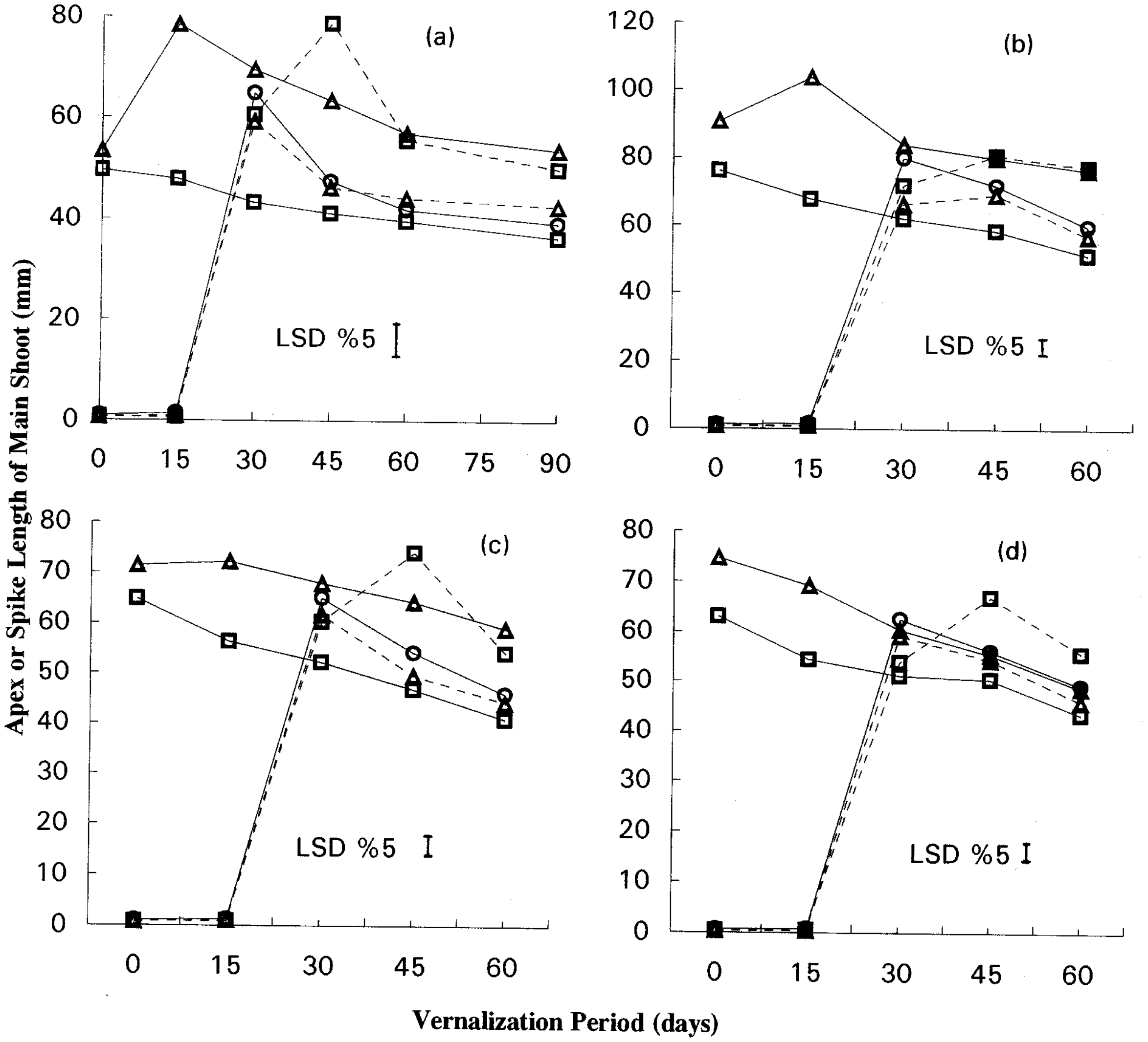

Figure 1. Effects of vernalization periods on apex or spike length in some wheat cultivars under short day-low light (a) and -high light (b) for 80-85 days and long day-low light (c) for 80-85 days and -high light (d) intensities for 65-70 days. (—□— Çukurova-86, —△— Atay-85, - - △ - - Lancer, - - □ - - Haymana-79, —○— Bezostaya-1)

18.8×10^4 day.μmolm^{-2}s^{-1} in low light intensity but 41.9×10^4 day.μmol m^{-2}s^{-1} in high light intensity. Therefore, spike development and ripe grain was obtained in short day-high light intensity.

In some plants of Haymana-79, whose vernalization requirement was found to be 45 days, supernumerary spikelet formation was observed in 30 days vernalization under short day-low light intensity. Wheats with a strong vernalization response have been found to have higher frequency of supernumerary spikelets than those with little or no response (24). Similar results were obtained in this research.

b) Effects of vernalization, photoperiod and light intensity on the length and diameter of main shoot

Shoot elongation starts at the floret primordium stage, accelerated from the terminal spikelet stage and influenced by environmental factors (day length, light intensity, temperature, etc.) throughout spike development (20). In all experiments, shoot formation was observed in control and vernalization treatments for Çukurova-86 and Atay-85, and in 30, 45 and 60 days of vernalization for winter cultivars. Shoot elongation was not observed in control and 15 days of vernalization for winter cultivars since they were in vegetative stage at that

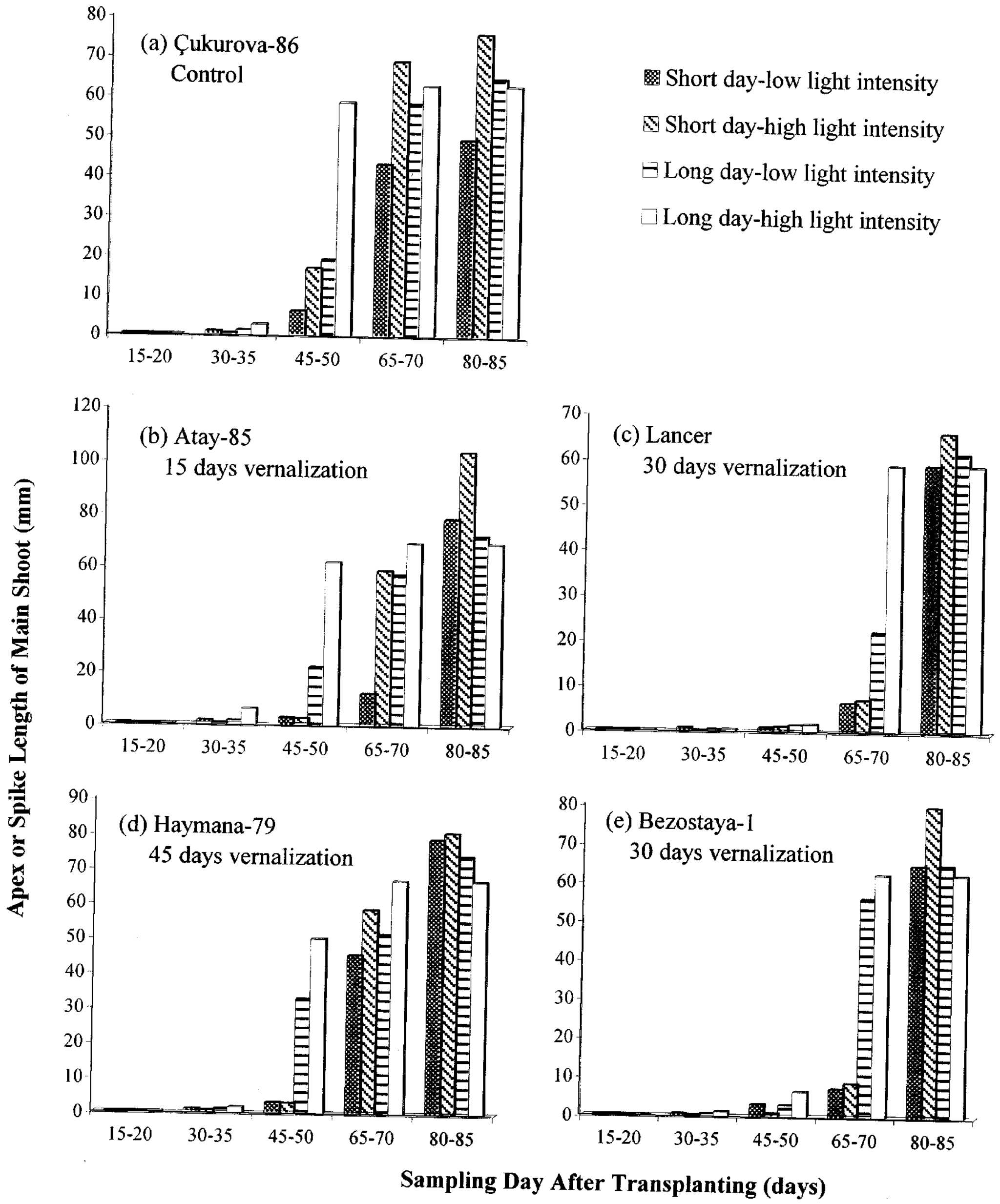

Figure 2. Variation in apex or spike length on main shoot in vernalization periods in which the longest spike length was found in some wheat cultivars under different photoperiod and light intensity experiment (Each column value is the mean of 9 plants)

time (Table 6). After required vernalization was applied to the cultivars, the length and diameter of the main shoot were decreased with increasing vernalization period (Table 6). Longer and thinner shoots were obtained in low light intensity than in high light intensity independent of photoperiod. This was attributed to the longer duration of the flower development stage in low light intensity, in which longer shoot elongation occurs. The shortest and thicker shoot formation occurring in short day-high light intensity was considered to be due to fast flower development in high light intensity.

The elongation rates and final length of shoot in green plants are usually higher under low light intensity than high light intensity (25). The shoot growth of most cereals is markedly stimulated shortly after floral initiation. In barley this rapid elongation begins at about the time of anther formation and appears to be associated with the production of large amounts of gibberellins,

Table 5. Effects of vernalization periods on the duration of ear emergence and total radiation in some wheat cultivars under different experimental conditions.

		Short Day-Low Light Intensity		Short Day-High Light Intensity		Long Day-Low Light Intensity		Long Day-High Light Intensity	
Cultivars	Vernalization Periods (day)	Days from Transplanting to Ear Emergence (day)	Total Radiation for Ear Emergence (x10^4 day.µmol.m^{-2}s^{-1})	Days from Transplanting to Ear Emergence (day)	Total Radiation for Ear Emergence (x10^4 day.µmol.m^{-2}s^{-1})	Days from Transplacnting to Ear Emergence (day)	Total Radiation for Ear Emergence (x10^4 day.µmol.m^{-2}s^{-1})	Days from Transplanting to Ear Emergence (day)	Total Radiation for Ear Emergence (x10^4 day.µmol.m^{-2}s^{-1})
Çukurova-86	0 (Control)	64	16.3	63	40.0	60	20.0	48	40.1
	15	55	14.0	55	35.0	49	16.4	41	34.2
	30	52	13.2	51	32.4	45	15.0	36	30.1
	45	48	12.2	46	29.2	45	15.0	33	27.6
	60	46	11.7	43	27.3	41	13.7	32	26.7
Atay-85	0 (Control)	94	23.9	81	51.4	68	22.7	60	50.1
	15	72	18.3	69	43.8	56	18.7	46	38.4
	30	66	16.8	60	38.1	51	17.0	41	34.2
	45	62	15.7	58	36.8	50	16.7	38	31.7
	60	61	15.5	56	35.6	47	15.7	37	30.9
Lancer	0 (Control)	-	-	-	-	-	-	-	-
	15	-	-	-	-	-	-	-	-
	30	75	19.1	85	54.0	73	24.4	69	57.6
	45	66	16.8	66	41.9	55	18.4	50	41.8
	60	54	13.7	55	34.9	45	15.0	38	31.7
Haymana-79	0 (Control)	-	-	-	-	-	-	-	-
	15	-	-	-	-	-	-	-	-
	30	78	19.8	82	52.1	70	23.4	57	47.6
	45	74	18.8	66	41.9	60	20.0	48	40.1
	60	59	15.0	56	35.6	46	15.4	39	32.6
Bezostaya-1	0 (Control)	-	-	-	-	-	-	-	-
	15	-	-	-	-	-	-	-	-
	30	80	20.3	84	53.3	70	23.4	59	49.3
	45	57	14.5	58	36.8	51	17.0	42	35.1
	60	55	14.0	50	31.8	47	15.7	37	30.9

*Each value giving in Table 5 is the mean of 9 plants.

which are rapidly utilized in the developing ear (26). Gibberellins are the metabolites responsible for shoot elongation. Long flower development stage in low light intensity may increase shoot length due to synthesis of gibberellins in this stage.

Conclusion

The vernalization and photoperiodic requirements of wheat cultivars are substantially different. Moreover, even if their vernalization requirement is provided, for ear emergence the required total radiation must also be provided at the end of the vernalization period. Determination of vernalization and photoperiodic requirements of breeding and registered wheat cultivars in Turkey is very important for recommendation of the most suitable sowing area and sowing time.

Therefore, the response of five wheat cultivars of different biological character to different vernalization and photoperiod treatments was investigated. After switching on the apex from the vegetative to the reproductive stage, the spike length increased as the vernalization period increased until the ear emergence stage. The longest spikes of Çukurova-86, Atay-85, Lancer and Bezostaya-1 and Haymana-79 were obtained in the control, and 15, 30 and 45 days of vernalization respectively in 12h.d^{-1} and 500μmol m^{-2}s^{-1} light intensity conditions. This was considered to be due to slower flower development in 12h.d^{-1} with the required radiation by high light intensity. Therefore, it is seems possible to improve wheat production under these conditions.

In the vernalization treatment where the longest spike of each cultivar was obtained, the stem length increased in low light intensity independent of photoperiod. The increase in stem length in low light intensity was attributed to a longer flower development stage in low light intensity than in high light intensity. On the other

Table 6. Effects of vernalization periods on main shoot length (cm) and diameter (mm) of some wheat cultivars under different experimental conditions.

		Short Day-Low Light Intensity		Short Day-High Light Intensity		Long Day-Low Light Intensity		Long Day-High Light Intensity	
Cultivars	Vernalization Periods (day)	The Length of Main Shoot (cm)	The Diameter of Main Shoot (mm)	The Length of Main Shoot (cm)	The Diameter of Main Shoot mm)	The Length of Main Shoot (cm)	The Diameter of Main Shoot (mm)	The Length of Main Shoot (cm)	The Diameter of Main Shoot (mm)
Çukurova-86	0 (Control)	36.58	1.94	34.64	2.26	38.82	2.14	31.52	1.70
	15	35.64	1.63	31.70	2.09	31.94	1.86	28.30	1.66
	30	32.54	1.58	31.53	1.92	30.94	1.76	27.16	1.66
	45	31.03	1.54	29.86	1.81	29.94	1.72	27.18	1.57
	60	30.46	1.39	27.67	1.81	28.01	1.51	26.24	1.32
	90	27.60	1.25						
Atay-85	0 (Control)	46.20	1.80	44.79	2.25	47.40	2.06	41.47	1.96
	15	50.76	1.82	48.13	2.32	46.87	1.93	38.08	1.81
	30	47.51	1.69	46.27	2.19	41.48	1.77	37.56	1.75
	45	44.88	1.62	43.96	1.96	40.42	1.73	38.98	1.71
	60	38.80	1.48	42.69	1.92	37.32	1.61	35.77	1.53
	90	38.77	1.40						
Lancer	0 (Control)	–	–	–	–	–	–	–	–
	15	–	–	–	–	–	–	–	–
	30	52.53	1.75	43.42	1.92	44.52	2.11	45.99	1.96
	45	49.51	1.61	47.21	1.83	49.14	1.77	38.41	1.67
	60	47.17	1.40	47.50	1.85	39.09	1.65	37.23	1.46
	90	41.81	1.21						
Haymana-79	0 (Control)	–	–	–	–	–	–	–	–
	15	–	–	–	–	–	–	–	–
	30	53.00	1.71	45.79	1.88	49.69	1.79	38.39	1.56
	45	56.37	1.82	53.49	1.99	57.60	2.04	44.50	1.87
	60	48.30	1.40	52.07	1.95	56.00	1.62	46.17	1.53
	90	43.01	1.42						
Bezostaya-1	0 (Control)	–	–	–	–	–	–	–	–
	15	–	–	–	–	–	–	–	–
	30	48.80	2.29	44.09	2.69	45.98	2.36	35.88	1.99
	45	48.37	1.91	42.01	2.44	39.30	1.82	34.56	1.86
	60	40.86	1.66	37.91	2.22	35.77	1.78	34.19	1.77
	90	35.99	1.51						
LSD (%5):		2.28	0.16	3.44	0.18	3.40	0.12	2.83	0.16

hand, the largest stem diameter of each cultivar was obtained in short day-high light intensity.

Vernalization caused early ear emergence by reducing the total radiation required for transition to the reproductive stage and to ear emergence. Excessive vernalization caused a decreaase in spike and stem length and stem diameter. Early sowing may cause excessive vernalization and hence short spike development in all cultivars. As a result, grain yield decreased due to infertile stamen formation.

Based on these results, the biological characters of the five cultivars were found as follows: Çukurova-86, spring, Atay-85, alternative, Lancer, Haymana-79 and Bezostaya-1, winter.

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