Duration of Pre-plant Chilling and its Effects on Garlic Cloving

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Abstract

Fall-planted garlic (*Allium sativum* L.) has higher clove number and higher overall productivity than spring-planted garlic. Most Saskatchewan garlic producers, however, spring-plant their crops to avoid losses associated with winterkill. Pre-plant storage temperature of cloves affects bulbing and cloving of the subsequent crop. Temperature and daylength during crop development also affect bulbing and cloving. Studies were conducted to determine the optimum duration of pre-planting chilling (4 ^{0}C) treatment for enhanced cloving and increased bulb yield of the spring-planted garlic cultivars (a local unnamed selection, 'California Early' and 'California Late'). In a greenhouse study, 'California Early' and 'California Late' cloves were planted after receiving chilling treatments of 4 ^{0}C for 0 (control), 30, 45, 60 and 75 days. For field studies, cloves from greenhouse-grown bulbs of all three cultivars were used and chilling treatments were similar to those for greenhouse studies.

Pre-plant chilling treatments of cloves produced significant increases in cloving and bulb yield for all cultivars. The treatment effect on cloving and bulbing of garlic in relation to cultivar and environment is discussed. Chilling treatment periods exceeding 30 days (for field) and 45 days (for greenhouse) resulted in an increase of cloving in bulbs of all cultivars. Improved cloving resulted in significant increase in both bulb diameter and bulb weight per plant, particularly in greenhouse-grown garlic. In conclusion, results indicate that improved cloving and bulb yields are obtained if cloves have been stored at 4^0 C for 45 and 60 days prior to field and greenhouse planting, respectively.

Introduction

Garlic (*Allium sativum* L.) is a well-known spice with antibacterial, and antiseptic properties that has been used world-wide since ancient times in folk medicine for the treatments of infectious diseases and for the prevention of stroke and atherosclerosis (Sendl 1995). The main edible parts of garlic are the bulbs, commonly known as “cloves”, which develop from axillary buds of the foliage leaves (Rahim and Fordham 1988). Garlic production on the Canadian Prairies is limited, yet there is strong local demand for garlic for fresh market and processing use (Waterer and Schmitz 1994). Garlic is exclusively vegetatively propagated using cloves because of its sterility (Novak 1990; Sendl 1995). The bulbing and cloving in garlic are influenced by daylength and the temperature to which the dormant cloves or growing plants are exposed before bulbing begins. In general, low initial temperatures followed by long days are essential for the formation of bulbs (Kolev 1962). The chilling requirement of garlic is generally fulfilled by overwintering in the field, but is limited in western Canada due to losses associated with extreme low winter temperatures. Spring planting therefore, is a popular practice among garlic growers in Saskatchewan. Most garlic growers use their own garlic as planting material, after storing at low temperatures (0-3 ^{0}C) for several months (Nyirfa 1999). Some growers, however, purchase from various sources where the bulbs may not have been properly stored and therefore have not adequately satisfied their chilling requirements. Consequently, the crop produces a higher percentage of poorly cloved and uncloved garlic bulbs known as “rounds”.

The chilling requirement for improved bulbing in garlic can be supplemented by artificial low temperature treatment of bulbs (Siddique and Rabbani 1985). Jones and Mann (1963) reported that exposure of dormant cloves or young plants to temperatures between 0 and 10 ^{0}C for 1 to 2 months hastens bulbing and those never exposed to temperatures below 20 ^{0}C failed to form bulbs and cloves. Siddique and Rabbani (1985) reported that treatment of mother bulbs at 6 ^{0}C for 50 days before planting increased the bulb size and bulb yield of garlic, particularly when the crop was planted late in the season. Information on pre-plant chilling requirement for improved cloving and higher bulb yield of spring-planted garlic cultivars grown in Saskatchewan is lacking. The present study therefore examined the minimum and optimum periods of chilling treatment (4 ^{0}C) required for improved cloving of garlic under greenhouse and field conditions in Saskatchewan.

Materials and Methods

Greenhouse Studies

This study was conducted using greenhouse-produced bulbs of two garlic cultivars, 'California Early' and 'California Late' which had not been stored at low temperatures prior to treatment. The garlic bulbs were cured at room temperature (22±2 ^{0}C) for about two weeks following harvest and then were placed at 20 ^{0}C, 70% RH until subject to chilling (low temperature) treatment. Garlic bulb samples containing about 50 sound cloves were periodically removed and placed at 4 ^{0}C, 70% RH such that different samples would receive 30, 45, 60 and 75 days of chilling treatments before planting in a greenhouse. Another sample of bulbs stored continuously at 20 ^{0}C, 70% RH was also planted to serve as the untreated control. Both treated and untreated cloves were planted in 500-mL pots filled with topsoil and Sunshine No.4, an artificial growing medium (1:1). The crop was grown in a greenhouse at 22±2 ^{0}C/16±2 ^{0}C (day/night) and a 16-h daylength with 600-700 μmol.m^{-2}.s^{-1} light intensity. Plants were fertilized once weekly with 20:20:20 (N: P: K) fertilizer mixture at 250 mg $^-$L at 50 mL per pot commencing the third week of planting. Each treatment consisted of ten replicates and each replicate consisted of four plants. Depending upon the cultivar, garlic bulbs were harvested about 105 to 120 days after planting, as the third leaf turned yellowish brown in color. The bulbs were cured at room temperature (22±2 ^{0}C) for about two weeks before evaluating the treatment effects on cloving and bulb yield.

Field Studies

Field studies were established in mid May of 1996 and 1997 at the Horticulture Field Research Plots in Saskatoon, SK, Canada (52^0 9' N LAT., 106^0 515 m elevation) on a Sutherland series clay soil, pH 7.1, with an EC<1.0 dS m^{-1}. Fertilizer was broadcast and incorporated prior to planting to bring soil fertility to 80 kg ha^{-1} N, 75 kg and ha^{-1} P_20_5. In both test years, the soils of the study sites were abundant in K (>350 kg ha^{-1} K_20). Greenhouse-produced bulbs of three garlic cultivars; a local unnamed selection, 'California Early' and 'California Late' which had not been stored at low temperatures prior to treatment were used as planting material for these studies. Garlic bulbs were exposed to different chilling treatment periods as described for greenhouse studies. The bulbs were cracked by hand immediately prior to planting, with sound cloves of each treatment were hand planted, 5-cm deep, with 10-cm within a row and 30 cm between row spacing. Rainfall was supplemented by irrigation. Weeds were controlled by mechanical and hand weedings. Each treatment consisted of three 2.4-m rows with 5 replicates in each year. The treatments were assigned in a randomized complete block design. Crop maturity was cultivar-dependent. In 1996, 'California Early', 'California Late' and the local selection were harvested on the 12th, 15th and 22nd of August, respectively. In 1997, however, both 'California Early' and 'California Late' were harvested on the 12th of August and the local selection was harvested on the 19th of August.

Data Collection and Statistical Analysis

Treatment effect on cloving and bulb yield of garlic cultivars were evaluated by determining the number of cloves/bulb, mean clove weight, mean bulb diameter, bulb weight/plant using four randomly selected bulbs from each experimental unit of greenhouse and field studies. The bulb yields of different treatments of the field studies were determined by harvesting 2-m long middle rows after eliminating borders; bulb yield was expressed in kg m^{-2}. Data were subject to analysis of variance (ANOVA) with 2x5 (cultivar x chilling treatment period) factorial for the greenhouse study, and 3x5 (cultivar x chilling treatment period) factorial for the field studies in a randomized complete block design using Minitab Statistical Software (Minitab Inc. PA, USA). Error variances for most tested variables differed over the two test years, therefore the data for each year were analyzed separately (Gomez and Gomez 1984). Treatment means were tested for significance by performing group comparisons (i.e., California cultivars vs. local selection, and ‘California Early’ vs. ‘California Late’) for cultivars and trend analyses (linear, quadratic and cubic components) for chilling treatment period and cultivar x chilling period interactions (Tables 1, 2, and 3).

Results

Greenhouse Study

Results revealed that on average, number of cloves/bulb, mean clove weight, and bulb weight of ‘California Early’ were comparable to those of ‘California Late’, but the bulb diameter of ‘California Late’ was significantly higher than that of ‘California Early’ (Table 1). The chilling treatment produced a marked impact on cloving and bulb yield of both cultivars (Table 1). On average, both linear and cubic components of the effect of chilling period were significant for clove number/bulb, bulb diameter and bulb weight of the garlic. Compared to the controls, those cloves receiving the chilling treatment for 45 days produced about a 3-fold increase in clove number/bulb in both cultivars, but further increase in the treatment period resulted in a marginal increase in clove number (Table 1). Increasing the treatment period resulted in quadratic and cubic change in the clove weight of garlic (Table 1). Of the plants raised from cloves, those receiving chilling treatment for 30 days produced about 1.4 times heavier cloves than the control, but further increase in the treatment period did not increase the clove weight in either cultivar (Table 1). The treatment effects on both bulb diameter and bulb weight followed a similar trend as for clove number. Of the plants raised from cloves, those receiving chilling treatment for 45 days produced about 1.5 times larger bulbs in diameter and over 3.5-fold increase in bulb weight compared to those of the respective controls (Table 1). However, further increase in the treatment period produced a plateau effect on the bulb size.

Field Studies

On average, number of cloves/bulb, clove weight and bulb diameters of California cultivars ('California Early' and 'California Late') were comparable to those of the local selection, for both years (Tables 2 and 3). In 1997, however, the number of cloves/bulb and bulb diameter of 'California Late' were significantly higher than 'California Early' (Table 3). In 1996, the average bulb yield of California cultivars was comparable to that of the local selection (Table 2), but in 1997 the local selection produced significantly higher bulb yield than that of the California cultivars (Table 3).

Chilling treatment produced a significant influence on cloving and bulb yield of the garlic cultivars in both years (Tables 2 and 3). Both linear and cubic components of the average effect of chilling treatment period on clove number/bulb of garlic were significant in both years (Tables 2 and 3). On average, those plants raised from cloves that received chilling treatment for 30 and 45 days increased clove number/bulb by over 2- and 4-fold, respectively compared to the controls, but further increases in the treatment period had only a marginal effect on cloving (Tables 2 and 3). The quadratic and cubic components of the California cultivars ('California Early'+'California Late') vs. local selection x treatment period interaction for clove number were significant for both years (Tables 2 and 3). Furthermore, linear, quadratic and cubic components of the 'California Early' vs. 'California Late' x treatment period interaction for clove number were significant for both years (Tables 2 and 3). These results further suggest that cloving of garlic in response to chilling treatment is cultivar-specific. A 30-day chilling treatment considerably improved cloving in both 'California Late' and the local selection whereas 'California Early' required over 30 days (<45 days) of chilling for the same effect on cloving. Chilling treatments exceeding 45 days had no major influence on cloving of either cultivar.

Both linear and quadratic components of the average effect of chilling treatment period on clove weight were significant for both years (Tables 2 and 3). This was due mainly to a sharp reduction in clove weight of the 30-day chilling treatment, compared to the control. However, the linear and quadratic components of the California cultivars ('California Early' + 'California Late') vs. local selection x treatment period interaction for clove weight were significant only in 1996. Plants of the local selection and California cultivars ('California Early' + 'California Late') produced 34% and 41%, respectively, lighter cloves in response to 30-day chilling treatments, compared to the respective controls. Further increase in treatment period had no major influence on clove weight (Table 2). Furthermore, linear component of the 'California Early' vs. 'California Late' x treatment period interaction for clove weigh was significant for both years (Tables 2 and 3).

On average, increasing chilling treatment period resulted in a linear decrease in bulb diameter of garlic in 1996, but the treatment had no effect in 1997 (Tables 2 and 3). With a few exceptions, most components of the cultivar x treatment period interaction for bulb diameter were not significant for both years (Tables 2 and 3). However, quadratic and cubic components of the California cultivars vs. local selection x treatment period interaction for bulb diameter were significant only in 1997 (Table 3). On average, the bulb diameter of California cultivars was reduced as treatment periods exceeding 45 days, whereas for the local selection, treatment effect was inconsistent, although most chilling treatments reduced the bulb diameter (Table 3).

Both linear and quadratic components of the average effect of the treatment period for bulb yield were significant for both years (Tables 2 and 3).

This was due mainly to the fact that increasing the chilling treatment period up to 45 days resulted in a consistent increase in bulb yield followed by a yield reduction due to further increase in treatment period. However, the linear and quadratic components of California cultivars vs. local selection x treatment period interaction for bulb yield was significant for both years and in addition, the cubic component of the interaction was also significant in 1996 (Tables 2 and 3). These results indicate that increasing treatment period up to 45 days resulted in a consistent increase in bulb yield in California cultivars followed by a slight yield reduction with further increase in treatment period. For the local selection, however, bulb yield increase occurred as a result of 30–day chilling period and further increase in the treatment period, but had no impact on bulb yield.

Conclusions

1. Pre-plant chilling treatment produced a significant impact on cloving in all garlic cultivars used in this study.

2. Treatment effects were cultivar-specific.

3. For improved cloving, California Early required a longer chilling period than other cultivars.

4. Field conditions partially satisfied the chilling requirements for cloving of garlic.

5. The optimum chilling period for field-grown garlic is 45 days and for greenhouse- grown is 60 days.

6. Bulbing and cloving are two different development processes in garlic.

7. Further studies are required to elucidate the factors affecting these two development processes.

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Table 1. Effect of duration of chilling treatment (4°C) on cloving and mean bulb weight of garlic cultivars, California Early and California Late under greenhouse conditions.

Treatment: Cultivar	Treatment: Chilling period (days)	Number of cloves/bulb	Mean clove weight (g)	Mean bulb diameter (cm)	Bulb weight (g) /Plant
California Early (C1)	0	1.1	2.7	2.3	3.4
	30	1.1	3.8	2.4	4.7
	45	3.7	2.6	3.5	11.4
	60	4.5	2.4	3.7	12.2
	75	4.3	2.7	3.6	13.0
	Mean	2.9	2.8	3.1	9.0
California Late (C2)	0	1.1	2.6	2.6	3.3
	30	1.2	3.5	2.8	5.1
	45	3.5	2.9	3.7	12.3
	60	4.1	3.0	4.4	14.6
	75	3.9	2.6	3.9	13.0
	Mean	2.8	2.9	3.5	9.7
	Statistical Significance				
	Cultivar (C1) vs. (C2)	ns	ns	**	ns
	Chilling period	L, C	Q, C	L, C	L, C
	Cultivar x Chilling period Interaction	ns	ns	ns	ns
	CV%	11.7	19.0	11.6	21.1

ns, and ** are non-significant at p=0.05 and significant at p=0.05, respectively.

L, Q and C are linear, quadratic and cubic effects, respectively.

Table 2. Effect of duration of chilling treatment (+4°C) on cloving and bulb yield of garlic cultivars, California Early and California Late and a local selection under field conditions in Saskatoon in 1996.

Treatment: Cultivar	Treatment: Chilling period (Days)	Number of cloves/Bulb	Mean clove weight (g)	Mean bulb diameter (cm)	Bulb yield (kg/m^2)
California Early (C1)	0	2.5	4.1	4.7	2.3
	30	3.7	2.7	4.5	3.3
	45	16.4	2.7	4.4	4.3
	60	16.8	2.6	4.2	3.7
	75	16.6	2.5	4.3	3.8
	Mean	10.4	2.9	4.4	3.5
California Late (C2)	0	3.6	5.7	5.1	3.5
	30	7.5	3.1	4.5	3.3
	45	13.9	2.4	4.6	4.0
	60	14.0	2.4	4.6	4.0
	75	14.7	2.4	4.6	3.8
	Mean	10.7	2.4	4.7	3.5
Local Selection (C3)	0	2.0	3.8	4.4	3.0
	30	7.7	2.5	4.7	4.5
	45	12.1	2.5	4.2	4.2
	60	13.5	3.2	4.4	4.0
	75	13.9	2.6	4.4	4.2
	Mean	9.9	2.9	4.4	4.0
	Statistical Significance				
	Cultivar				
	C1+C2 vs. C3	ns	ns	ns	ns
	C1 vs. C2	ns	ns	**	ns
	Chilling period	L, C	L, Q	L	L, Q
	C1+C2 vs. C3 x Chilling period	Q, C	L, Q	ns	L,Q, C
	C1 vs. C2 x Chilling period	L, Q, C	L	ns	ns
	CV %	16.7	30.7	8.2	11.6

ns, and ** are non-significant at $p=0.05$ and significant at $p=0.01$, respectively.
L, Q and C are linear, quadratic and cubic effects, respectively.

Table 3. Effect of duration of chilling treatment (+4°C) on cloving and bulb yield of garlic cultivars, California Early and California Late and a local selection under field conditions in Saskatoon in 1997.

Treatment: Cultivar	Treatment: Chilling period (Days)	Number of cloves/Bulb	Mean clove weight (g)	Mean bulb diameter (cm)	Bulb yield (kg/m^2)
California Early (C1)	0	2.8	4.2	4.4	2.2
	30	3.7	2.5	4.2	3.3
	45	11.9	2.5	4.8	4.0
	60	15.2	2.4	4.4	3.5
	75	15.0	2.5	4.4	3.3
	Mean	9.7	2.9	4.4	3.3
California Late (C2)	0	3.8	5.6	4.8	1.8
	30	7.6	3.4	4.9	3.3
	45	13.3	2.5	4.6	3.8
	60	13.5	2.3	4.6	3.5
	75	14.4	2.4	4.4	3.5
	Mean	10.5	3.2	4.7	3.2
Local Selection (C3)	0	2.1	4.6	4.2	3.2
	30	7.4	2.5	4.1	3.8
	45	12.2	2.4	3.8	3.8
	60	13.7	2.9	3.4	3.7
	75	13.7	2.5	4.6	4.0
	Mean	9.8	3.0	4.5	3.7
	Statistical Significance				
	Cultivar				
	C1+C2 vs. C3	ns	ns	ns	**
	C1 vs. C2	*	ns	*	ns
	Chilling period	L, C	L, Q	*	L, Q
	C1+C2 vs. C3 x Chilling period	Q, C	ns	Q, C	L, Q
	C1 vs. C2 x Chilling period	L, Q, C	L	ns	ns
	CV %	13.2	25.0	9.1	12.4

ns, and ** are non-significant at p=0.05 and significant at p=0.01, respectively.
L, Q and C are linear, quadratic and cubic effects, respectively.