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INFLUENCE OF CHLORMEQUAT CHLORIDE ON FIVE WINTER BARLEY CULTIVARS

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ABSTRACT

A field experiment was undertaken to examine the effects of foliar application of chlormequat chloride (2-chloroethyl-trimethyl ammonium chloride, CCC) on growth, development and yield of five winter barley (*Hordeum vulgare* L.) cultivars (Arass, Victoria, Alger-Seres, Probest Dwarf and Valfajr). The results indicated that despite the concomittant start of reproductive phase in all cultivars, timing and duration of developmental stages were significantly different among the cultivars. Chlormequat chloride increased the survival of tillers and therefore, the number of ears, and despite partial decrease in individual grain weight, the grain yields of CCC-treated plots were significantly higher than the untreated controls due to higher spikelet survival per spike. Chlormequat chloride increased phytomass production in all cultivars except Probest Dwarf, with no significant effect on harvest index. Alger-Seres produced the highest grain yield and Valfajr the lowest. This was associated with the highest phytomass production in Alger-Seres with no significant difference in harvest index. Also, the grain number per plant was the highest in Alger-Seres while there was no significant difference in mean kernel weight with the other cultivars. Better understanding of the responses of widely grown barley cultivars to chlormequat chloride needs further investigation.

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تاثیر کلرمکوات کلرید بر پنج رقم جو پاییزه

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به ترتیب استاد یار و دانشجوی سابق کارشناسی ارشد بخش زراعت و اصلاح نباتات دانشکده کشاورزی دانشگاه شیراز، شیراز، ایران.

چکیده

در یک آزمایش مزرعه ای تاثیر کاربرد کلرمکوات کلرید (۲-کلرواتیل تری متیل آمونیوم کلرید، CCC) بر رشد، نمو و عملکرد پنج رقم جو پاییزه (ویکتوریا، آلجرسرس، پروبست دووارف، ارس و والفجر) مورد بررسی قرار گرفت. نتایج حاصل نشان داد که گر چه دوره رشد زایشی در همه رقم ها به طور هم زمان آغاز شد اما زمان وقوع و طول دوره مراحل نمو بین رقم ها متفاوت بود. کلرمکوات کلرید آهنگ نمو را در همه رقم ها کاهش داد. همچنین CCC بقای پنجه های بارور و در نتیجه تعداد سنبله در هر بوته را افزایش داد و با وجود کاهش نسبی میانگین وزن هر دانه، عملکرد کرت های تیمار شده با CCC به دلیل افزایش بقای سنبلک ها در هر سنبله، به طور معنی داری زیادتر از عملکرد کرت های شاهد بود. کلرمکوات کلرید تولید ماده خشک را در تمام رقم ها (به جز رقم پروبست دووارف) ، بدون اینکه تاثیر معنی داری بر شاخص برداشت رقم ها بگذارد، افزایش داد. بیشترین عملکرد دانه از رقم آلجرسرس به دست آمد و کمترین عملکرد مربوط به رقم والفجر بود. این امر به دلیل تولید ماده خشک بیشتر در رقم آلجرسرس، بدون تغییر معنی داری در شاخص برداشت آن نسبت به رقم والفجر بود. همچنین بیشترین تعداد

دانه در هر بوته در رقم آلجرسرس به دست آمد، بدون این که تغییر معنی داری در میانگین وزن هر دانه آن نسبت به رقم های دیگر پدید آید. درک دقیق تر واکنش ارقام مهم و پر محصول جو به CCC، نیازمند مطالعه و بررسی بیشتری است.

INTRODUCTION

Since their first practical applications in the early 1960s, the importance of plant growth retardants in agriculture has steadily increased. The success of chlorocholine chloride (chlormequat, CCC, 2-chloroethyl-trimethyl ammonium chloride) and other "cationic" retardants in straw shortening , and so in reducing or preventing lodging, ensured their wide commercial use in the late 1960s (3, 5, 17), i.e., in a period when lodging was perhaps a serious problem in many wheat (*Triticum aestivum* L.) cultivars (9). Although the introduction of semi-dwarf wheats largely solved the problem of lodging, evidence was already accumulating that a timely application of a retardant such as chlormequat could increase yield of both wheat and barley, independently of any control of lodging (e.g. 9, 17).

In barley, a carefully timed application of CCC at a prescribed stage of apical development has been reported to increase the grain yield through increasing grain number (5, 6, 8, 10, 14). Such increases in grain number have in turn been found to be the result of an increase in the number of fertile shoots (ears) (2, 8, 10, 11, 19), and/or in the number of grains per ear (4, 6, 19). Yield increases achieved through increased ear number following the timely application of CCC have been attributed to the transient retardation of spike development and culm elongation in more advanced shoots (2, 11, 19) thus lessening and/or delaying their acquisition of dominance (1, 12, 19) and resulting in an increased within-plant uniformity (8, 15).

Such increased sink size, i.e., increased potential grain number as a result of CCC application, will only be beneficial to yield when it is associated with a similar increase in the size and/or activity of the source (i.e., photosynthetic organs) so that a higher rate of phytomass accumulation would be achieved in almost all situations in which CCC application is correctly timed but whether or not this increase in grain number will be realized as an increased grain yield depends on environmental conditions after anthesis which determine grain size (i.e. mean kernel weight). This is probably why there are conflicting reports on yield increase following the application of CCC (e.g., 3)

Despite the widespread use of growth retardants such as CCC on small grains in Europe, little is known about their possible beneficial effects on grain yield and its components when applied to new barley cultivars in Iran. The purpose of the present study was to investigate the effects of the growth retardant CCC, on growth and developmental processes of five winter barley cultivars during the pre-anthesis phase and its relation to final grain yield and its components.

MATERIALS AND METHODS

A "miniplot" experiment was conducted with five winter barley cultivars (Victoria, Probest Dwarf, Alger-Seres, Arass and Valfajr) at the Experimental Farm of the College of Agriculture, Shiraz University, Shiraz, Iran ($29^0 36'$ N and $52^0 32'$ E). The term miniplot refers to a small (3×2 m) plot which is evenly fertilized and compacted. Miniplots enable very uniform stands of plants at exactly prescribed spacings to be raised with minimum within-plot variability so that with a "frequent small harvest" sampling procedure, small or transient effects of treatments on growth and development can be detected (Fig. 1). The experimental design was a randomized complete block with four replicates. There were 10 treatments [(i.e., 2 plant growth regulator treatments (with or without)$\times$5 cultivars]. Seeds were graded by sieving and a single grade (3-3.25 mm) of them with 99% germination rate was hand sown through perforated plywood sheets in rows 15 cm apart. The space between the seeds within each row was 5 cm to give the exact density of 134 plants m^{-2}. Uniformity of sowing depth was achieved by using a hand dibber to make holes 5 cm deep. Seedlings which failed to emerge were quickly replaced with matched spares (raised in individual containers) to obtain the exact density.

Nitrogen and phosphorus were applied to all the miniplots as urea and ammonium phosphate to the seed bed each at the rate of 100 kg ha^{-1}. No herbicide was necessary since plots were regularly hand weeded . At ZGS 30 (21), 120 days after sowing (DAS) additional urea was top dressed at the rate of 50 kg ha^{-1}.

The CCC treatment was applied as " Arotex Extra" at 1610 g (a.i.) ha^{-1} with a precision sprayer (Pressure 3 bar). Rigid screens were used to prevent spray drift. The CCC was applied at " the double ridge" of the most advanced spikelet [Ds=2.0 according to Waddington *et al.* (20)] when the initial ear was less than 15 mm long and the true stem length was about 7-10 mm. No node was detectable and tillering was going on in all cultivars.

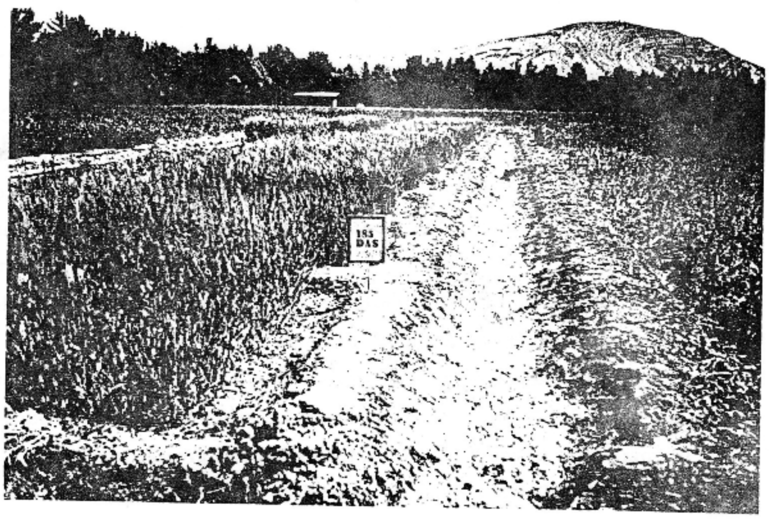

Fig 1. Views of the miniplots of barley cultivars 185 days after sowing.

During the growing season frequent small harvests (at 5-day intervals) were taken from pre-designated sampling stations. Each station was surrounded by at least two guard rows. These frequent small samples, which continued to be taken up to anthesis (judged by another dehiscence) were mainly intended to monitor apical development but they also provided some information on dry matter production and partitioning.

Within each plot, an area of 25×30 cm (with guard rows) was marked and left undisturbed for harvesting at crop maturity. On this final harvest sample, phytomass production was measured and yield component analysis was carried out. Dry weights were recorded after the plant material had been oven-dried at 80 ^{0}C for 48 hours. The data were analyzed by analysis of variance and the means compared by honestly significant difference test (HSD).

RESULTS

Effects of CCC on Shoot Growth and Development

The short term responses of "early" (i.e. at double ridge stage) CCC application were generally similar in all cultivars and included retardation, of apical development of the main shoot and also the retardation of elongation of leaf sheaths and true stems (Table 1). However, this retardation of stem elongation was transient and during the rapid ear growth phase (i.e. between booting and anthesis) the trend was reversed and the CCC treated plants caught up with the controls (Table 2). As shown in Fig. 2 the leaf area per plant which was initially smaller in CCC- treated plants caught up with the controls and by anthesis, i.e. when the number of fertile shoots per plant was fixed, the CCC treated plants had greater leaf area.

Early CCC initially slowed the rate of apical development of the main shoot without any effect on its spikelet initiation rate. However, the peak spikelet number in CCC-treated plants tended to be greater (50 and 45 for treated and control, respectively). This suggests that the spikelet initiation phase continued for a longer period (5 days) in CCC treated plants (Fig. 3).

This trend of greater number of spikelets was carried through until anthesis (171 days after treatment), when the number of potential grain sites in CCC treated plants was significantly higher than controls.

Table 1. Short term effects of application of CCC at the double ridge stage of the main shoot measured 20 days after treatment.

Plant growth regulator	Cultivar				
	Victoria	Probest Dwarf	Alger-Seres	Arass	Valfajr
			Apex length (mm)		
Control	2.81	2.42	2.44	2.76	1.83
CCC	2.67 NS†	2.13 NS	2.24 NS	2.37 *§	1.46 *
			Pseudostem height (mm)		
Control	72.43	73.85	92.16	84.76	68.37
CCC	60.76 *	62.53 *	78.58 *	73.08 *	57.07 *
			True stem height (mm)		
Control	19.92	18.62	24.67	21.73	16.81
CCC	14.92 *	14.68 *	15.07 *	15.72 *	10.53 *
			Dry weight (g $plant^{-1}$)		
Control	0.49	0.40	0.49	0.49	0.42
CCC	0.44 NS	0.45 NS	0.48 NS	0.46 NS	0.33 NS

† NS = Nonsignificant.

§ * = Significant at 5% level.

Tillering responded to CCC rather quickly, so that only 10 days after treatment, treated plants of all cultivars had significantly higher number of tillers and this trend was carried through until anthesis (Fig. 4).

Table 2. Phenology of winter barley cultivars treated with chlormequat chloride or untreated.

Treatment	Tillering (ZGS 13,21-18,29)	Stem elongation (ZGS 31-34)	Booting (ZGS 45)	Ear emergence (ZGS 55)	Anthesis (ZGS 61-69)
Control	74-141†	129-152	157	164	171-176
CCC	74-141	131-155	159	165	171-175

† Values indicate the number of days from sowing.

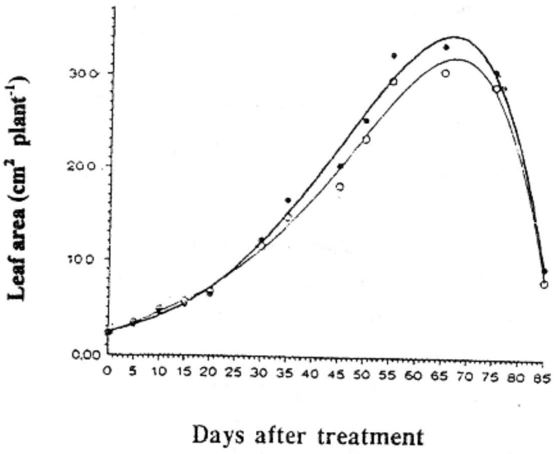

Fig 2. Effect of early CCC on leaf area per plant. Open and shaded symbols represent control and CCC treatments, respectively.

Effects of CCC on Grain Yield and its Components

In the absence of CCC, there was a significant difference in grain yield among the cultivars, Alger-Seres produced the highest grain yield (Table 3). This higher grain yield was the result of a higher grain number, which in turn was due to both a greater number of grains per ear and more ears per plant. Data collected before anthesis showed that the percentage of spikelet mortality in Alger-Seres was significantly lower than in other cultivars (20% compared to 24, 25 and 48% in Victoria, Probest Dwarf, Arass and Valfajr, respectively). The higher grain number in Alger-Seres was associated with no significant change in mean grain weight (Table 3), but was associated with a greater biological yield (i.e. total above ground biomass). There was no significant difference in harvest index except with Probest Dwarf (Table 3).

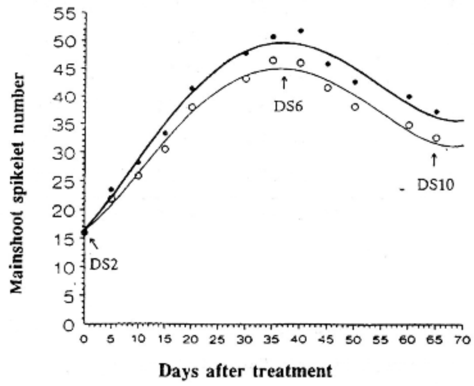

Fig 3. Effect of early CCC on the main shoot spikelet number. Open and shaded symbols are for control and CCC treatments, respectively. For DS description see Waddington *et al.* (20).

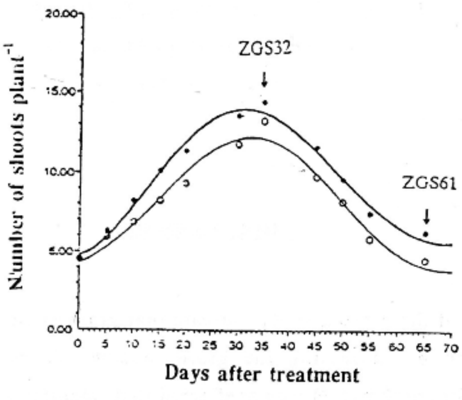

Fig 4. Effect of early CCC on number of shoots per plant. Open and shaded symbols represent control and CCC treatments, respectively. For ZGS description see Zadoks *et al.* (21).

Table 3. Grain yield and its components, phytomass and harvest index in five winter barley cultivars in the absence of CCC.

Yield and yield components	Cultivar				
	Victoria	Probest Dwarf	Alger-Seres	Arass	Valfajr
Grain yield (g plant^{-1})	4.462c†	5.188b	5.697a	5.082b	4.206c
Grain number plant^{-1}	111.2b	111.5b	136.9a	116.0b	102.5b
Ear number plant^{-1}	4.60a	5.20a	5.23a	4.47b	3.97b
Grain number ear^{-1}	24.18a	22.25b	26.19a	25.97a	25.82a
Mean grain weight (mg)	42.71a	44.17a	42.86a	42.51a	44.36a
Biological yield (g plant^{-1})	10.07b	10.31b	12.88a	12.32a	9.84b
Harvest index (%)	44.28b	50.31a	44.86b	41.23b	42.15b

†. Means followed by the same letter in each row are not significantly different at $P \leq 0.05$.

Chlormequat chloride increased the grain yield of all cultivars, but not significantly in Probest Dwarf (Table 4). The higher grain number with CCC application was mainly the result of increased ear number (in Alger-Seres and Arass), number of grains per ear (in Valfajr), or both (in Victoria) (Table 4). Such increases in grain number were partly compensated for by reductions in mean grain weight (Table 4),

The increased grain yield with early CCC treatment was associated with a significant increase in biological yield in all cultivars except for Probest Dwarf (Table 5). As shown in Table 5, CCC had no significant effect on harvest index.

DISCUSSION

The results of the present study indicate that grain yield of winter barley can be increased by increasing the grain number, the component largely determined before anthesis. It was confirmed that manipulation of sink size is possible during the early reproductive phase, i.e., when a small reduction in the rate of spike development and therefore, stem elongation in the leading shoots results in greater within-plant shoot uniformity giving a higher rate of tiller survival and/or increased within-ear uniformity giving higher spikelet survival through reduced "tip death". These findings are consistent with the conclusion of other workers (e.g. 2, 5, 10, 12, 13, 14, 16).

Table 4. Effects of CCC on grain yield and its components in five winter barley cultivars.

Yield and yield components		Cultivar				
		Victoria	Probest Dwarf	Alger-Seres	Arass	Valfajr
Grain yield g plant^{-1}	Control	4.462	5.188	5.597	5.082	4.206
	CCC	5.378*†	5.453^{NS§}	6.228*	5.984*	4.936*
Grain number plant^{-1}	Control	112.2	111.5	136.9	116	102.5
	CCC	155.5*	129.3^{NS}	177.5*	155.3*	136.5*
Ear number plant^{-1}	Control	4.60	5.20	5.23	4.47	3.97
	CCC	5.63*	5.43^{NS}	6.31*	5.57*	4.53^{NS}
Grain number ear^{-1}	Control	24.18	22.25	26.19	25.97	25.82
	CCC	27.63*	23.82^{NS}	28.13^{NS}	27.89^{NS}	30.14*
Mean grain weight (mg)	Control	42.71	44.17	42.86	44.36	42.51
	CCC	36.16*	42.92^{NS}	37.34*	40.68^{NS}	37.83*

† * = Significant, at %5 level.

§ NS = Nonsignificant difference with corresponding controls.

The results also demonstrate that the increased sink size with CCC treatment was associated with a proportional increase in phytomass, thus confirming the previous findings of other researchers (e.g., 2, 18, 19) who showed that increases in number of potential grain sites following CCC or mepiquat chloride (1, 1-dimethyl-piperidinium chloride) treatment were associated with a higher phytomass production later, in pre-anthesis and during the post-anthesis period . Indeed, such "vigorous" late growth appears to be an important part of the response to CCC. It is obvious that phytomass response can only be achieved when conditions for crop photosynthesis and growth are favorable, i.e., when "sink size" is the only limiting factor. The apparently conflicting response on partial regulation of source activity by the demands of the sink reflect the most often ignored influence of the environmental factors which may be limiting the "source size". For example, the observation of Jenner (7) that adverse conditions during early grain setting can prevent grain thinning from increasing the weight of the remaining grains, emphasizes the role of environment in determining the magnitude of response to manipulation of sink or source. Further investigation is needed for better understanding the mechanism of beneficial effects of chlormequat chloride on newely-introduced wheat and barley cultivars under different agroclimatic conditions of Iran.

Table 5. Effect of CCC on phytomass production and harvest index in five winter barley cultivars.

Cultivar	Phytomass yield (g plant^{-1})		Harvest index (%)	
	Control	CCC	Control	CCC
Victoria	10.07	11.64*†	44.28	46.19^{NS§}
Probest Dwarf	10.31	11.41^{NS}	50.31	47.76^{NS}
Alger-Seres	12.88	14.36*	44.86	43.37^{NS}
Arass	12.32	14.26*	41.23	41.93^{NS}
Valfajr	9.84	12.23*	42.15	40.01^{NS}

† * = Significant, at %5 level.

§ NS= nonsignificant difference with corresponding controls.

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