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Full Length Research Paper

Comparative Analysis of *Lactuca sativa* Cultivars for Optimal Winter Growth in Hydroponic Systems

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Soilless cultivation of lettuce gained popularity in recent years in South Africa because of improved yield and quality. Thirteen crisphead lettuce cultivars were evaluated in a gravel-film production system during the winter season at the experimental farm of the ARC-Roodeplaat. The experiment was laid out as a randomized complete block design with five replicates. For each cultivar, yield, internal quality, compactness, uniformity, ribbing, tip-burn, disease tolerance, bolting tolerance and number of days to maturity were recorded. The cultivars were ready for harvest from 70 - 77 days after transplanting. Results showed clear differences between cultivars, with four cultivars, namely Del-Rio, Patagonia RZ, Winter haven and Winter Supreme, out yielding the rest of the cultivars included in the trial. These four cultivars were also more tolerant to tipburn and disease, compared to most other cultivars included in the trial. Cultivars Annie, Del Rio, Supreme Plus and L425 showed the best core ratio, combined with a good colour and tip burn resistance. Results, thus, indicate that variability in yield and quality of crisphead lettuce are determined by cultivar differences, changes in environmental conditions, as well as different production systems utilized by farmers. Improved yield and quality can be obtained by selecting the correct cultivars for winter production in a soilless medium.

Key words: Gravel-film technique, quality, yield, growing season.

INTRODUCTION

Lettuce has caught the vegetable grower's attention in South Africa, since it has become increasingly popular as a vegetable in salads. This popularity has led to an increase in lettuce production and consumption in urban areas (Maboko and Du Plooy, 2007). Lettuce is usually consumed raw, has a high calcium, iron and vitamin A content, as well as high nutrient value (Niederwieser, 2001; Maboko, 2007). It is a good source of vitamins and often prescribed for overweight people because of its low kilojoules content. Soundy and Smith (1992) emphasized the importance of cultivar evaluation under various cultivation conditions, since most cultivars are imported into South Africa, with limited knowledge on the optimal cultivation requirements of specific crisphead lettuce cultivars. Wrong choices can lead to great financial losses.

During the hot summer months of South Africa, certain crisphead lettuce cultivars have poor head development, are bitter, and bolt due to high soil and ambient tempe-ratures. Maboko and Du Plooy (2007) showed that culti-vation of crisphead lettuce during summer in a soilless medium also results in poor head formation, since higher temperatures encourage leaf development and not head formation, although certain cultivars are better adapted to high temperatures.

Cool growing seasons are optimal for lettuce cultiva-tion, with temperatures ranging from 7 to 24^{o}C, with an average of 18^{o}C (Lorenz and Maynard, 1988). The sum-mer production of lettuce, where temperatures are above 24^{o}C, results in the development of physiological dis-orders such as ribbiness, rib discoloration and bolting (Rayder, 1999; Jenni, 2005). Not much information is available on the performance of crisphead lettuce culti-vars in a gravel-film cultivation system. This study was, thus, conducted to assess quality and yield of 13 winter crisphead lettuce cultivars.

Cultivated in a closed recirculating system, that is, the

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Table 1. An alphabetical list of crisphead lettuce cultivars used to assess their performance when cultivated in a closed system, that is, the gravel-film technique. The distributors of the seed in South Africa are also indicated.

Crisphead cultivars	Company
Annie	Seminis
Del-Rio	Hygrotech
Duke	Conatech (Pty) Ltd
L306	Starke Ayres
L425	Starke Ayres
L427	Starke Ayres
L428	Starke Ayres
Patagonia RZ	DICLA
PF 1283	Premier
Supreme Plus	Seminis
Trinity	Premier
Winterhaven	Ferax
Winter Supreme	Sakata Seeds Southern Africa

Table 2. Composition and chemical concentration of fertilizers (Hygroponic and Calcium nitrate) used for lettuce production.

Types of fertilizer	Composition	Concentration (g/kg)
Hygroponic	Nitrogen (N)	68 g/kg
	Phosphate (K)	42 g/kg
	Potassium	208 g/kg
	Magnesium (Mg)	30 g/kg
	Sulphur (S)	64 g/kg
	Iron (Fe)	1.254 g/kg
	Copper (Cu)	0.022 g/kg
	Zinc (Zn)	0.149 g/kg
	Manganese (Mn)	0.299 g/kg
	Boron (B)	0.373 g/kg
	Molybdenum (Mo)	0.037 g/kg
Calcium Nitrate	Nitrogen (N)	117 g/kg
	Calcium (Ca)	166 g/kg

the gravel-film technique.

MATERIALS AND METHODS

Materials and methods were similar to a summer production trial as reported by Maboko and Du Plooy (2007). The trial was conducted in a 40% shade-net house at the ARC- Roodeplaat, South Africa (25, 59 S; 28, 35 E and at an altitude of 1200 m above sea level). Thirteen selected crisphead lettuce cultivars were cultivated during the winter season (Table 1). The seeds were sown in 300 cavity polystyrene trays. The growth media used was Hygromix® and vermiculite was used to cover the seeds after seeding.

Seedlings were transplanted 28 days after seeding. The experimental area was 20.4 x 16 m. The seedlings were planted in 2 x 1 m plots, at a plant spacing of 25 x 25 cm to give a plant population of 160 000/ha. There were 32 plants per plot. The experiment was laid out as a randomized complete block design with five replicates.

A gravel-film technique hydroponic system was utilized to perform the trial. The plantlets were transplanted 6 cm deep in gullies filled with crushed granite rocks of irregular shape with diameters ranging from 16 to 19 mm. Each gully was 1 m wide and 17 m in length. A balanced nutrient solution (Table 2) was pumped to the top of the gullies where four tubes released the nutrient solution at a rate of 700 ml/tube per minute, day and night. The gravel-film technique is based on the nutrient film technique system, where a nutrient solution flows down gullies by gravitational flow. The slope of the gullies are between 2.5 to 3% to allow efficient flow of the nutrient solution in a thin layer (3 mm) back into the reservoir, from where it is pumped back to the gullies.

The pH and EC of the nutrient solution was measured daily using a pH and EC meter (HANNA Instruments, and maintained within a range of 5.8 to 6.1 and 1.9 to 2.1 mS/cm, respectively.

Temperature readings of the nutrient solution were measured daily at 12 h:30 at the end of the gullies using a thermometer. The climatic data collected during the period of cultivar evaluation are presented in Table 3.

During harvest, 12 plants of each plot, cultivar were collected for yield determination and five uniform heads were cut longitudinally for internal quality assessment. Head diameter, head length, stem length and stem diameter were recorded. The core ratio was determined by calculating the ratio of stem length to head length.

The number of days from transplanting to harvesting was also recorded. Compactness, colour, ribbing, tip- burn, bolting and disease tolerance, uniformity and internal quality were evaluated on all 12 heads from each plot using a scale of 1 - 5, where:

1 = very poor
2 = poor
3 = moderate
4 = good
5 = very good

Data was analyzed using the statistical program GenStat (2003). Differences between cultivars were tested by analysis of variance (ANOVA). Treatment means were separated using Fishers' protected t-test least significant difference (LSD) at the 5% level of significance (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Data showed significant differences (P<0.05) among lettuce cultivars tested within each variable. Both Table 4 and 5 indicate a wider separation of means, although most cultivars did not differ significantly from each other. Subsequently, the performances of different cultivars were divided into three groups, that is, high (H), interme-diate (I) and low (L) (Tables 4 and 5).

High yield, uniformity of plants in the production sys-tem, high percentage harvest of marketable heads, bolt-ing tolerance, resistance to disease, attractive green colour and relatively short internal stem are considered as important quality parameters. Other parameters include good compactness, internal quality, ribbing resis-tance, tip-burn and (Maboko and Du Plooy, 2007). Among all winter cultivars evaluated, there were cultivars that did not exhibit all of these quality determining para-meters.

High yielding cultivars for winter production were

Table 3. Monthly temperature and relative humidity values during the trial period (June to August 2007) in a shade-net house at the Agricultural Research Council (ARC) - Roodeplaat experimental farm.

Month	Nutrient solution temperature (^{o}C) in gullies (at 12h:30)		Ambient temperature (^{o}C)			% Relative humidity		
	Min	Max	Min	Ave	Max	Min	Ave	Max
May	16	21.0	-7.1	14.4	39.0	0	48.8	100
June	13	18.0	-3	11.1	32.7	0	39.6	100
July	13	22.0	-5.8	11.2	36.1	0	46.9	100
August	15	21.0	-2.3	14.4	41.5	0	50.8	100

Table 4. Performance of 13 crisphead lettuce cultivars cultivated in a gravel-film system during winter season, June – August 2007 at ARC-Roodeplaat experimental farm.

Cultivar	Mean yield (t/ha)	Mean head mass (g)	Head length (mm)	Head diameter (mm)	Percentage harvest	Stem length (mm)	Core ratio
Annie	80.5 I^{bc}	503.3 I^{bc}	159.0 I^{cd}	143.9 I^{c}	100 H^{a}	46.4 I^{cd}	0.29 H^{def}
Del-Rio	97.6 H^{a}	610.0 H^{a}	180.8 H^{a}	154.5 H^{ab}	100 H^{a}	50.1 I^{c}	0.28 H^{ef}
Duke	85.4 I^{b}	533.5 I^{b}	154.5 I^{e}	139.8 I^{cd}	100 H^{a}	47.7 I^{c}	0.31 I^{cde}
L306	87.5 I^{b}	546.6 I^{b}	159.6 I^{cd}	135.2 I^{d}	100 H^{a}	58.2 I^{b}	0.39 I^{b}
L427	73.3 I^{cd}	458.4 I^{c}	143.6 L^{f}	125.7 L^{e}	100 H^{a}	41.2 I^{de}	0.29 H^{def}
Patagonia RZ	105.9 H^{a}	661.6 H^{a}	185.2 H^{a}	147.6 H^{bc}	100 H^{a}	61.8 L^{b}	0.34 I^{bc}
Supreme Plus	88.0 I^{b}	550.1 I^{b}	167.8 I^{bc}	145.7 I^{c}	100 H^{a}	39.5 H^{e}	0.24 H^{g}
Winterhaven	100.3 H^{a}	626.7 H^{a}	177.9 H^{a}	158.8 H^{a}	100 H^{a}	80.6 L^{a}	0.45 L^{a}
L428	58.3 L^{e}	364.6 L^{e}	138.8 L^{f}	118.1 L^{ef}	98.34 H^{a}	36.2 H^{e}	0.26 H^{fg}
Winter Supreme	102.3 H^{a}	639.4 H^{a}	176.1H^{ab}	160.2 H^{a}	98.34 H^{a}	73.5 L^{a}	0.42 L^{a}
Trinity	48.2 L^{f}	301.0 L^{f}	140.8 L^{f}	113.6 L^{f}	98.34 H^{a}	37.0 H^{e}	0.26 H^{fg}
L425	75.8 I^{c}	473.7 I^{c}	157.4 I^{e}	125.7 L^{e}	93.36 I^{b}	38.4 H^{e}	0.24 H^{g}
PF1283	64.4 L^{de}	402.7 L^{de}	141.9 L^{f}	113.1 L^{f}	93.34 I^{b}	45.4 I^{cd}	0.32 I^{cd}
LSD $_{0.05}$	8.974	56.09	9.21	7.89	4.91	5.20	0.036

Figures within the same column followed by the same letter in superscript are not significantly different (P>0.05), using Tukey's comparison test. The performance of different crisphead lettuce cultivars with regards to the various parameters investigated was divided into groups: High (H), Intermediate (I) and Low (L)

Patagonia RZ (105.9 t/ha), Winter Supreme (102.3 t/ha), Winterhaven (100.3 t/ha) and Del-Rio (97.6 t/ha) (Table 4). Low yielding cultivars were PF1283 (64.4 t/ha), L428 (58.3 t/ha) and Trinity (48.2 t/ha). According to Mabokoand Du Plooy (2007), the high yielding cultivars for summer production, when grown under soilless conditions, yielded from 75 - 80 t/ha. Thus, the data obtained in this study clearly indicates that the best culti-vars selected for winter production out yielded the best cultivars selected for summer production in the study per-formed by Maboko and Du Plooy (2007). These results emphasize the effect of climatic environment on head development and the importance of cultivar selection for different production seasons.

With crisphead lettuce, head mass normally determines yield, as is the case in this study where the four highest yielding cultivars having the highest head mass, that is, Patagonia RZ (661.6 g), Winter Supreme (639.4 g), Winterhaven (626.7 g) and Del-Rio (610.0 g) (Table 4). Cultivars with an intermediate mean head mass were Supreme Plus (550.1 g), L306 (546.6 g), Duke (533.5 g), Annie (503.3 g), L425 (473.7 g) and L427 (458.4 g). Undersized mean head mass producing cultivars were PF1283 (40.7 g), L428 (364.6 g) and Trinity (301.0 g), resulting in poor yield.

Crisphead lettuce cultivars with longer heads and larger head diameter, generally indicates a good marketable head size of high quality. Cultivars that indicate poor qua-lity, as a result of unmarketable size, are those with shorter and narrower heads. Among the cultivars evalua-ted, the longer heads were observed with the high yield-ing cultivars Patagonia RZ (185.2 mm), Del-Rio (180.8

Table 5. Performance of 13 crisphead lettuce cultivars cultivated in a gravel-film technique during winter season, June-August 2007 at ARC-Roodeplaat experimental farm.

Cultivar	Colour (1-5)	Tip-burn resistance (1-5)	Disease tolerance (1-5)	Internal quality (1-5)	Ribbing resistance (1-5)	Uniformity (1-5)	Compactness (1-5)	Days to maturity
Annie	4.6 H^{ab}	4.4 H^{bc}	4.6 H^{abc}	3.8 I^{bcd}	4.6 H^{abc}	4.6 H^{ab}	3.7^{cd}	74
Del-Rio	4.8 H^{ab}	4.6 H^{ab}	4.4 H^{abc}	3.6 I	4.2 H^{cd}	4.0 H$_{abcd}$	3.2^{ef}	74
Duke	4.4 H^{bc}	4.4 H^{bc}	4.2 I^{bcd}	4.0 H^{bc}	4.0 H^{de}	4.0 H^{abcd}	4.1^{b}	74
L306	4.6 H^{ab}	5.0 H^{a}	4.6 H^{abc}	3.8 I^{bcd}	4.4 H^{bcd}	4.4 H^{abc}	3.7^{cd}	71
L427	3.6 L^{d}	4.0 I^{c}	3.6 I^{de}	3.6 I^{cd}	3.6 I^{e}	4.0 H^{abcd}	3.8$_{bcd}$	70
Patagonia RZ	5.0 H^{a}	5.0 H^{a}	4.8 H^{ab}	3.6 I^{cd}	5.0 H^{a}	4.8 H^{a}	4.0^{bc}	74
Supreme Plus	4.8 H^{ab}	4.4 H^{bc}	5.0 H^{a}	4.0 H^{bc}	4.8 H^{ab}	4.6 H^{ab}	3.8$_{bcd}$	71
Winterhaven	4.0 I^{cd}	5.0 H^{a}	4.2 I^{bcd}	4.0 H^{bc}	4.0 H^{de}	3.6 I^{cd}	4.0^{bc}	77
L428	4.0 I^{cd}	4.0 I^{c}	4.0 I^{cd}	3.4 I^{d}	3.0 I^{f}	3.4 I^{d}	3.0$_{bcd}$	70
Winter Supreme	4.8 H^{ab}	5.0 H^{a}	4.4 H^{abc}	4.2 H^{b}	4.0 H^{de}	4.6 H^{ab}	4.1^{b}	77
Trinity	4.0 I^{cd}	3.2 L^{d}	3.2 L^{e}	4.0 H^{bc}	4.0 H^{de}	3.6 I^{cd}	4.0H^{bc}	70
L425	4.6 H^{ab}	4.8 H^{ab}	4.6 I^{abc}	4.0 H^{bc}	4.4 H^{bcd}	3.8 I^{bcd}	3.5^{de}	71
PF1283	4.0 I^{cd}	3.4 L^{d}	4.0 I^{cd}	5.0 H^{a}	3.6 I^{e}	3.2 I^{d}	4.7H^{a}	72
LSD $_{0.05}$	0.53	0.54	0.64	0.50	0.55	0.81	0.35	-

Figures within the same column and followed by the same letter in superscript are not significantly different (P>0.05), using Tukey's comparison test

mm), Winterhaven (177.9 mm) and Winter Supreme (176.1 mm) (Table 4). The shortest heads were observed in PF1283 (141.9 mm), Trinity (140.8 mm) and L 428 (138.8 mm). The largest head diameters were observed in Winter Supreme (160.2 mm), Winterhaven (158.8 mm), Del-Rio (154.5 mm) and Patagonia RZ (147.6 mm). The narrowest head diameters were observed in PF 1283 (113.1 mm), L 425 (125.7 mm), Trinity (113.6 mm), L428 (118.1 mm) and L427 (125.7 mm). Cultivars that are considered unmarketable might be suitable for markets that sell individually wrapped lettuce (Soundy and Smith, 1992). Most of the cultivars tested did show a high percentage harvest, with the exception of L425 (93.4%) and PF 1283 (93.3%). The main reason for the relative low harvest percentage in these two cultivars was due to off type plants.

Jenni et al. (2003) reported that a shorter internal stem indicates higher quality crisphead lettuce. Cultivars that had the longest internal stem length were Winter Supreme (73.52 mm), Winterhaven (80.64 mm) and Patagonia RZ (61.80 mm), while Supreme Plus (39.53 mm), L 428 (36.24 mm), Trinity (37 mm) and L425 (38.36 mm) had the shortest internal stem length. Maboko and Du Plooy (2007) reported that the shortest stem length of summer cultivars ranged from 90 - 110 mm and the longest by as much as 154 mm, indicating an inferior quality, compared to winter production. Shorter internal stem length (49 mm) was reported by Jenni et al. (2003) when crisphead lettuce was grown in white polyethylene mulch, compared to silver polyethylene mulch (55.0 mm) and a bare soil (57.8 mm) during summer. These results indicate that stem length increased with an increase in temperature.

The highest core ratios were recorded for cultivar L306 (0.37), Winterhaven (0.45) and Winter Supreme (0.42), while shortest core ratios were recorded for Supreme Plus (0.24), L428 (0.26), Trinity (0.24), L425 (0.24), Annie (0.29), Del-Rio (0.28) and L427 (0.29) (Table 4). According to Maboko (2008), internal stem growth should not be more than half that of the head length, that is, it should not have a core ratio of more than 0.50 (stem length to head length) . A core ratio of more than 0.50 indicates that the plant is not growing in a favourable environment (Maboko, 2008). All cultivars tested in this winter trial had an acceptable core ratio, which indicates favourable growing conditions and resistance to bolting. Maboko and Du Plooy (2007) found the lowest core ratio among culti-vars tested during summer production with an average monthly ambient and nutrient solution temperature of 15 to 44^{o}C and 26 to 29^{o}C, respectively, to be as high as 0.61, indicating an increase in stem length and core ratio by higher ambient and nutrient solution temperatures. They concluded that cultivar choice is influenced by a specific growing temperature, either ambient or nutrient temperature, for quality head development.

The performance of crisphead lettuce cultivars during winter production in terms of bolting and disease tolerance, colour, tip- burn and ribbing resistance, internal quality, uniformity and compactness, were acceptable according to the ratings (Table 5). Cultivar L428 had a loose head compared to other cultivars. Early maturing cultivars were ready for harvesting 70 days after transplanting in winter production. However, Soundy and Smith (1992) found most cultivars maturing at 120 days for early winter sowing. This may indicate that lettuce grown in a soilless production system tend to mature ear-lier as compared to in-soil production. Crisphead lettuce cultivars took even less time to mature in summer (about 40 days) as a result of high ambient temperatures (Maboko and Du Plooy, 2007). The results indicate that both the production season and the production system have an effect on the maturing time of the different cultivars, as well as on internal quality and yield.

All cultivars tested exhibited an attractive green colour. Cultivars Trinity and PF1283 had some incidence of tip-burn at the leaf edges. Cultivar Trinity did show incidence of powdery mildew at the lower leaves which resulted in yellowing and dying off of the infected leaves. Cultivar L428 had poor internal quality with inner leaves that were loosely compact and yellowed.

All cultivars tested had good ribbing resistance with the exception of cultivar L428. Poor uniformity was observed for cultivar L428 and PF1283, compared to other cultivars which exhibited good uniformity. Cultivar Del-Rio and L425 had a problem of compactness, that is, loose heads.

Conclusions

The results of this trial indicate that Del Rio, Patagonia RZ, Winterhaven and Winter Supreme have the highest yield for winter production. Cultivars Annie, Del Rio, Supreme Plus, and L425 have the best core ratios com-bined with a good colour and tip burn resistance. How-ever, it should be noted that the results presented here are only for data collected during one season and in a gravel-film production system, thus, these results are only applicable to production in a gravel-film production system. It should not be extrapolated to other production systems, such as soil cultivation. Low yielding cultivars, as indicated by undersized head mass, might be suitable

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for markets that prefer smaller sized heads. Future studies should include different production systems and different production areas. A wider range of cultivars can then be recommended to farmers to suite both the pre-vailing environmental conditions and the production sys-tems used by these farmers.

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