Technique for Improving Marketable Yield and Quality of Hydroponically Forced Witloof Chicory

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Abstract. A method was developed to improve the yield and quality of chicons of witloof chicory (*Cichorium intybus* L.) forced hydroponically from roots taken following long-term storage. The method combines the use of a resilient material (polyurethane foam) with the application of pressure to the developing chicons. At the start of forcing, weights of 0, 150, 300, 450, and 900 g/root were applied to the crown and maintained until harvest. Marketable yields and density of chicons of the late-forcing cultivar Faro increased with increasing weight applied. Increasing weight also significantly decreased the length : diameter ratio of chicons, an indicator of quality. Increased marketable yield and improved quality of 'Bea' (intermediate to late-forcing cultivar) chicons were achieved with application of 450 g/root. The technique provides a tool for improving economic yields of late-season, hydroponically forced witloof chicory.

Traditional methods for forcing witloof chicory involve the placement of roots in a bed of soil followed by covering roots with a soil-based medium (Nunhems Zaden, 1985; Ryder, 1979). Huyskes (1963) selected cultivars that would produce relatively tight chicons in the absence of soil covering. This breeding innovation led to great savings in labor formerly required for removing soil from chicons. Further improvement and testing of genotypes suited to forcing without cover (Lipps, 1976; Sarrazyn, 1976) enabled the development of methods for the hydroponic forcing of witloof chicory. This method depends on production of tight, well-shaped chicons in the absence of a cover. Hydroponic forcing is currently the most common method of commercial production in Holland, France, and in the United States. In Belgium, the scale of most forcing operations is relatively small, and many growers employ traditional forcing methods.

Some forcing operations attempt to provide chicons throughout the entire year. To achieve this goal, roots must be maintained in storage for long durations. Yield and quality of chicons are often quite low when roots

are forced late in the season or when storage conditions are suboptimum. Also, roots harvested at an improper stage of maturity or supplied with excessive N nutrition may lead to development of poor quality chicons (Daemen, 1987). Decreased quality is commonly exhibited by a large percentage of open or loosely packed chicons. Growers who use soil covering in their forcing operations frequently claim that chicons are tighter, denser, and generally are of higher quality than those grown without soil cover, conventionally or hydroponically. Perhaps the mechanical stress imposed on the developing chicons from the pressure exerted by a soil cover aids in the development of a tighter chicon. If so,

it would be possible to develop mechanical techniques to improve the quality of hydroponically forced chicons. Our objective was to determine if pressure applied to the developing chicons would increase the marketable yield and quality of chicons forced from roots following long-term storage.

Roots of the cultivars Faro and Bea were grown in South Deerfield, Mass., in Summer 1988 and were harvested on 28 Sept., 120 days from planting. The day before harvest, shoots were trimmed to ≈ 5 cm above the crown. Following harvest, roots were held in storage at $1 \pm 2^\circ\text{C}$. Before forcing, roots were trimmed to 15 cm with ≈ 3 cm of senesced shoot remaining from harvest. Separate forcing experiments were initiated on 15 Mar. and 14 Apr. 1989 in a cold storage room maintained at $11 \pm 1^\circ\text{C}$. The forcing solution consisted of 2.7 mM $\text{Ca}(\text{NO}_3)_2$, 2.6 mM MgSO_4 , and 8.7 mM KNO_3 (De Proft et al., 1986) and was maintained to a depth of 5 cm in wooden trays (Corey et al., 1990). The solution was adjusted periodically to pH 7.0 by additions of HCl.

Samples of 15 roots of 'Faro' were weighed and packed into plastic pots (11.4 cm high $\times$ 15 cm diam) that then were placed in the forcing tray. Each pot had four 1.5-cm holes in the bottom and fourteen 1.5-cm holes in the sides for adequate ventilation of roots and circulation of nutrient solution. A 7.6-cm-thick piece of polyurethane foam (air dry density = 0.017 g/cm^3) was placed on top of the shoots to provide a cushion for application of downward pressure. Individual pieces of 1.8-cm-thick plywood were placed on top of the foam pieces (excluding control) to provide a uniform pressure when bags of sand, were placed on top of the plywood. Foam and plywood pieces were weighed, and quantities of sand were placed in polyethylene bags to provide 0 (control), 150, 300,

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Fig. 2. Compression of polyurethane foam used as a growth cushion for treatments involving applied weight to developing chicons. Points represent means of two replications. Arrows denote regions of the curve corresponding to treatments used considering an average cross-sectional area of 9.6 cm² for the root crown.

Fig. 3. Appearance of untreated (control) and treated (450 g/root) chicons of 'Faro' on the day of harvest.

Fig. 4. Effect of applied weight on percent marketable chicons ($r = 0.78$; $P = 0.022$) and marketable yield ratio ($r = 0.80$; $P = 0.017$) of chicons of 'Faro'. Points represent means of duplicate 15-root samples.

and 450 g/root of applied weight. For example, a bag of sand weighing 1990 g was

placed on top of wood and foam pieces having a combined weight of 260 g to provide

a 150 g/root treatment to 15 roots. Selection of treatments was based partly upon assumptions made to simulate initial pressures occurring at the beginning of conventional forcing with soil covering. The following calculation was made. An average root crown diameter of 3.5 cm and a soil cover of 10 cm give a volume of soil of $\approx 96 \text{ cm}^3$ above the crown. With a soil bulk density of 1.5 g/cm³ and a moisture content of 25% (w/w), a total soil weight of 175 g would cover a single root. Treatments were not expressed as pressures because of the dynamics and irregularities of the forces involved and the variability in the cross-sectional area to which the downward forces were applied. The concept for the technique is illustrated in Fig. 1.

Two replications (pots) of each treatment were arranged in randomized complete blocks. Each pot contained 15 roots. Treatments were initiated at the beginning of forcing and were maintained until harvest 28 days later. Chicons were harvested flush with the crown and their total weight measured. A random sample of 10 chicons was selected for further measurements. Individual chicons from the random samples were weighed and measured for maximum circumference and length. Chicons were then wrapped and sealed in a plastic film and their volume measured by water displacement. Density was calculated from the weight and volume measurements. Chicons were unwrapped, trimmed, and graded to obtain a marketable yield ratio (marketable weight : total weight). The percentage of marketable chicons was based on the total number of roots forced. Chicons that were malformed, unfurled, or weighed <60 g (Sterrett and Savage, 1989) were considered unmarketable.

Two additional experiments were conducted. One involved the use of 0, 450, and 900 g/root applied to 'Faro'. Another experiment was conducted using 0 and 450 g/root treatments and 'Bea' and 'Faro'. Two replications of each treatment were used in both experiments. Other procedures for forcing and measurements were the same as those described.

To determine the compressibility of the foam, two pieces, each 60 cm², were cut. A piece of 1.3-cm-thick plywood was placed over the foam, and weights ranging from 500 g to 5000 g were placed on the plywood. The thickness of the foam was measured after application of each weight.

Compression of the foam at the start of the forcing depended on the pressure applied (Fig. 2). The 150 g/root treatment ($\approx 1.5 \text{ kPa}$) compressed the foam very little (<1 cm). As chicons developed and exerted growth forces, additional compression of the foam occurred, and the chicons pushed the entire load upward. The 300 g/root treatment was near the middle of the region of maximum changes in the rate of compression (initial compression of $\approx 3.5 \text{ cm}$) and the 450 g/root treatment compressed the foam by $\approx 5 \text{ cm}$, $\approx 65\%$ of the compressed thickness (Fig. 2). For these treatments, developing chicons encountered increased resistance to growth ear-

Fig. 5. Relationships of LD ratio (quadratic; $R^2 = 0.88$) and density (quadratic; $R^2 = 0.83$) of 'Faro' chicory with weight applied during forcing. Points represent means of duplicate 15-root samples.

Table 1. Effects of weight applied to developing chicory of 'Faro' and 'Bea' chicory on yield and quality.

Treatment variable	Response variable ^a			
	Marketable chicory (%)	Marketable yield ratio	LD ratio of chicory	Density of chicory (g/cm ³)
Cultivar	NS	**	NS	NS
Faro	79	0.72	2.58	0.61
Bea	73	0.60	2.52	0.62
Weight	+	**	**	**
None	71	0.59	2.85	0.56
450 g/root	80	0.73	2.24	0.66
Cultivar × wt	NS	NS	NS	*

^aValues represent means of four observations for the treatment variables cultivar and weight. Each observation was the mean of a sample of 35 and 29 roots for 'Faro' and 'Bea', respectively. LD = length : diameter.

+, **, NS Statistically significant at $P = 0.1$, 0.05 , and 0.01 and not significant, respectively.

lier than when 150 g/root was applied. However, growth forces were more than sufficient to overcome the pressures applied.

At harvest, ungraded chicory of the 450 g/root treatment exhibited the highest visual quality (Fig. 3). Untreated chicory appeared longer and looser than any of those from treatments involving applied weight. Total yield of ungraded chicory was not significantly affected by treatment (overall mean = 86 ± 8 g/chicory). However, percent marketable chicory and marketable yield ratio increased linearly with increasing weight applied ($r = 0.78$; $P \leq 0.022$ and $r = 0.80$; $P \leq 0.017$, respectively), 450g/root giving the highest economic yields (Fig. 4). Since marketable yield did not plateau within the 0 to 450 g/root range, a follow-up experiment included a 900 g/root treatment to determine if further improvements in marketable

yield could be obtained. Application of 900 g/root resulted in significantly fewer marketable chicory (69%) than 450 g/root (86%) and about the same as the control (73%), suggesting that the maximum response is probably near 450 g/root for the size and physiological status of 'Faro' roots used in the experiments.

Marketable yield ratio increased more with increasing weight applied than did percent marketable chicory (Fig. 4). This result was due to the higher quality chicory and decreased trim loss obtained from application of weight. Improved quality also was reflected in the decreased length : diameter ratio (LD ratio) and increased density of chicory with increasing weight applied (Fig. 5). Significant trends for both responses presented are second-order polynomials. Even the lowest weight (150 g/root) resulted in

significantly shorter, stockier chicory than those receiving no application of weight.

The technique also improved the yield and quality of 'Bea' chicory (Table 1). 'Faro' produced a significantly higher marketable yield ratio than 'Bea' regardless of treatment, but quality of chicory as measured by LD ratio and density was similar for both cultivars. Application of weight resulted in an increased density of 0.14 g/cm^3 for 'Faro' compared to an increase of only 0.06 g/cm^3 for 'Bea', illustrating the nature of the cultivar × weight interaction.

Despite breeding efforts to select genotypes suited to forcing without cover, significant improvement in economic yields and quality of hydroponically forced witloof chicory is still achievable using manipulations of cultural practices. A simple technique involving the application of mechanical pressure to developing chicory significantly improved marketable yields and quality of intermediate- and late-forcing cultivars. Suitability of the technique applied to different stages of maturity, storage durations, and cultivars remains to be evaluated. Finally, it will be of basic interest to understand the physiological mechanisms upon which the success of the technique is based.

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