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Provitamin A, Nutrient Analysis, and Plant Growth of Hydroponically Grown Swiss Chard Cultivars

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Abstract. **Leafy crops, like Swiss chard, are known to be natural sources of provitamin A, but little is known which cultivars and plant parts have greater amounts. Swiss chard 'Fordhook Giant', 'Oriole', 'Peppermint', 'Rhubarb', 'Heart of Gold', 'Cardinal', 'Sea Foam', 'Bright Yellow', 'Silverbeet', and 'Bright Lights' were grown using the hydroponic nutrient film technique. Data were collected on soil plant analysis development (SPAD), plant growth, provitamin A content, and nutrient analysis. SPAD was greatest for 'Heart of Gold'. Shoot fresh weight was greatest for 'Peppermint', 'Sea Foam', and 'Bright Yellow'. Leaf provitamin A content was greatest in 'Fordhook Giant', but was only different from 'Oriole', 'Cardinal', and 'Sea Foam'. Provitamin A content was greater in petioles than in leaves for all cultivars except for 'Fordhook Giant' and 'Bright Yellow', whereas nutrient content was greater in leaves than petioles except for potassium. Thus, Swiss chard cultivar selection by growers will affect yield and consumer nutrition.**

Swiss chard (*Beta vulgaris* L.) is a leafy green commonly grown for its spinachlike leaves and thick, fleshy petioles (Gamba et al. 2021). Petioles can grow in a variety of colors, including white, red, yellow, orange, pink, and purple (Parkell et al. 2016). These plants also contain a large amount of many important nutrients (Gamba et al. 2021) and are also a great source of provitamin A (Rana 2016). The quality and yield of leafy green crops can be improved when grown in a hydroponic system (du Plooy et al. 2012). Sgherri et al. (2010) reported that basil (*Ocimum basilicum* L.) plants show increased provitamin content when grown in a hydroponic system compared with plants grown in a soil system.

Although provitamin A is most commonly associated with meat and dairy products, most of the provitamin A in human diets comes from plants (US Department of Health and Human Services 2023). In plant tissues, vitamin A is found in the form of β-carotene, which gets converted into vitamin A within the body (Rucker 2001). This β-carotene is what gives plants their yellow, orange, and red color. Vitamin A, or retinoic acid, is an extremely important factor in maintaining healthy tissues and cells (Ross 2010). Provitamin A deficiency can increase susceptibility to diseases and infections, reduce childhood growth, and cause xerophthalmia, a disease that causes blindness (Sommer 2008). This study evaluated different-color Swiss chard cultivars for plant growth and provitamin A content as salad greens.

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Materials and Methods

Growth conditions and plant material. The experiment was conducted at the Oklahoma State University research greenhouses in Stillwater, OK, USA. No supplemental lighting was used in the greenhouse, and daily light integral levels averaged 12.4 ± 2.1 $mol \cdot m^{-2} \cdot d^{-1}$. The greenhouse temperature was set at 21/18 °C (day/night) but averaged 20.9 ± 3.7 °C. Relative humidity averaged 53 ± 4.2%.

Seeds of 10 cultivars of Swiss chard included 'Oriole', 'Heart of Gold', 'Bright Lights', 'Peppermint', 'Fordhook Giant', 'Bright Yellow', 'Rhubarb Chard' (Johnny's Selected Seeds, Winslow, MN, USA), 'Cardinal' (Pinetree Garden Seeds, New Gloucester, ME, USA), 'Five Color Silverbeet' (Baker Creek, Mansfield, MO, USA), and 'Sea Foam' (Pinetree Garden Seeds). Seeds were sown on 31 Oct 2023 in oasis cubes (Harris Seeds, Rochester, NY, USA) of size 1.5 cm^3 and kept under the mist bench at the Greenhouse Learning Center in Stillwater, OK, USA.

Seedlings were transplanted from the mist bench to the nutrient film technique (NFT) table (Growers Supply, Dyersville, IA, USA) on 28 Nov 2023. Each NFT table had 10 channels measuring 10 cm wide × 5 cm deep × 900 cm long, and each channel lid had 18 of the 2.5-cm site holes, spaced 20 cm on center. Each table had one plant per slot and 10 plants per cultivar arranged randomly. The tables had a slope of 2.8% and the water was collected in a tank and recirculated by pump to the irrigation pipe. Nutrient solution was prepared using 5N–5.2P–21.6K fertilizer (Jack's; J.R. Peters, Allentown, PA, USA) with secondary and micronutrients, and calcium nitrate (American Plant Products, OK City, OK, USA). Tanks were filled to a 40-gal capacity and 147.4 g of Jack's along with 97.5 g of calcium nitrate were added initially according to the recommended rates. The pH of the nutrient solution was maintained at 5.5 to 6.5, and the electrical conductivity (EC) level was maintained between 1.5 and 2.5 $mS \cdot cm^{-1}$. The pH down-solution (General Hydroponics, Santa Rosa, CA, USA), which uses phosphoric acid, was used to lower the pH because of alkaline tap water, and additional nutrient solution was added whenever the EC was low.

Data collection. Plant greenness using a soil plant analysis development (SPAD) meter (Konica Minolta, Japan), plant height, plant width (average of two perpendicular measurements), and number of leaves of each plant were measured 37 d after transplanting. Three readings were taken from the leaf tip of one mature leaf in the middle of the plant for SPAD. Shoots and roots were separated to get fresh weights, and were then dried for 7 d at 53.9 °C to acquire dry weight measurements. At the end of each study, leaf nutrient concentration was measured using petioles or leaves from three bulked plants per sample by the Soil, Water, and Forage Analytical Laboratory in Stillwater, OK, USA, and analyzed as outlined by Zhang and Henderson (2016).

Determination of provitamin A content. Provitamin A was determined using an enzyme-linked immunosorbent assay kit (CSBE07038Pl, Plant Provitamin A ELISA Kit; Cusabio, Houston, TX, USA). Fresh samples from a mature, fully developed leaf or petiole were cut into small pieces; 500 mg was used. Four samples were homogenized with 4.5 mL phosphate-buffered saline buffer (ThermoFisher, Waltham, MA, USA) at a 1:9 ratio of buffer to plant sample (4.5 μL per 500-mg sample). Homogenous extract solutions were centrifuged at 4 °C and 4600 g_n for 7 min. Then, 50 μL of the extract solution was used. Two sets of standards were employed to calibrate the assay. The absorbance at 450 nm was measured with a spectrophotometer microplate reader (Epoch; Bio-TEK, Instruments Inc., Winooski, VT, USA).

Experimental design and statistical analysis. The study was conducted in a completely randomized design with six replications. Statistical analysis was performed using SAS/STAT software (ver. 9.4; SAS Institute, Cary, NC, USA). Tests of significance were reported at the 0.05, 0.01, and 0.001 levels. The data were analyzed using generalized linear mixed-models methods. Tukey multiple comparison methods were used to separate the means.

Results and Discussion

A significant cultivar difference was observed for SPAD, plant width, number of leaves, shoot fresh weight, root fresh weight,

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Table 1. Least square means cultivar differences in growth and quality of several different Swiss chard cultivars grown in nutrient film technique hydroponic systems at Oklahoma State University research greenhouses in Stillwater, OK, USA, in 2023.

Cultivar	SPAD	Plant ht (cm)	Plant width (cm)	No. of leaves	Shoot fresh wt (g)	Shoot dry wt (g)	Root fresh wt (g)	Root dry wt (g)	Leaf provitamin A ($ng \cdot mL^{-1}$)	Petiole provitamin A ($ng \cdot mL^{-1}$)
Fordhook Giant	32.0 bc[i]	9.2 a	10.8 ab	7.7 ab	41.0 b	2.6 bc	9.2 a	0.7 b	18.2 a	13.4 a
Oriole	28.4 d	9.2 a	10.1 ab	6.9 b–d	37.7 bc	2.5 bc	8.8 a	0.7 bc	5.6 b	11.5 a
Peppermint	32.6 b	9.7 a	10.0 ab	8.0 a	51.0 a	3.5 a	8.3 a–c	0.8 a	9.5 ab	10.9 a
Rhubarb	31.5 b–d	8.3 a	9.8 b	7.0 b–d	32.2 c	2.3 c	7.3 cd	0.6 cd	12.2 ab	14.0 a
Heart of Gold	37.0 a	8.6 a	9.4 b	7.0 b–d	30.2 c	2.3 c	5.5 f	0.5 d	15.2 a	20.0 a
Cardinal	30.2 b–d	8.4 a	10.3 ab	7.5 a–c	29.5 c	2.3 c	6.0 ef	0.6 b–d	4.6 b	19.1 a
Sea Foam	31.9 bc	9.5 a	11.9 a	6.8 cd	51.0 a	3.4 a	8.4 a–c	0.7 b	4.0 b	7.4 a
Bright Yellow	29.1 cd	9.3 a	10.3 ab	6.7 d	51.3 a	3.4 a	7.8 b–d	0.6 b–d	15.1 a	12.1 a
Silverbeet	29.9 b–d	8.5 a	10.3 ab	7.4 a–d	36.5 bc	2.6 bc	5.9 ef	0.6 bc	15.6 a	19.4 a
Bright Lights	29.6 b–d	8.2 a	10.8 ab	6.7 d	41.2 b	3.0 ab	7.0 de	0.6 b–d	14.0 a	16.6 a
Significance	<0.0001	0.0548	0.0049	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0025	0.2474

[i] Means (n = 10 except for vitamin A, where n = 4) within a column followed by the same lowercase letter are not significantly different by pairwise comparison in a mixed model ($P \leq 0.05$).

SPAD = soil plant analysis development.

Table 2. Least square means cultivar differences in nutrient analysis of several different Swiss chard cultivars grown in nutrient film technique hydroponic systems at Oklahoma State University research greenhouses in Stillwater, OK, USA, in 2023.

Cultivar	Organ	Total N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe ($mg \cdot mL^{-1}$)	Zn ($mg \cdot mL^{-1}$)
Fordhood Giant	Leaves	5.2 a[i]	1.7 a–c	6.7 c	1.3 ab	1.5 a	0.5 a	100.1 a	52.6 a
	Petioles	4.0 b	0.9 d	12.4 a	0.3 c	0.6 b	0.1 b	85.9 ab	26.6 b
Oriole	Leaves	5.0 a	1.5 a–c	6.9 c	1.3 ab	1.5 a	0.5 a	95.1 a	44.3 a
	Petioles	4.0 b	0.8 d	10.3 b	0.3 c	0.8 b	0.2 b	18.9 b	19.6 b
Peppermint	Leaves	5.0 a	2.3 a	8.0 bc	1.4 ab	1.4 a	0.5 a	96.5 a	51.2 a
	Petioles	4.1 b	1.0 cd	11.5 ab	0.3 c	0.6 b	0.2 b	20.0 b	25.9 b
Rhubarb	Leaves	4.9 a	1.9 ab	8.3 bc	1.3 ab	1.4 a	0.5 a	106.8 a	54.4 a
	Petioles	4.2 b	0.8 d	11.7 a	0.4 c	0.7 b	0.1 b	19.3 b	23.2 b
Heart of Gold	Leaves	5.1 a	1.7 a–c	6.5 c	1.3 ab	1.6 a	0.5 a	97.3 a	48.4 a
	Petioles	4.0 b	0.9 d	9.5 b	0.3 c	0.8 b	0.2 b	28.3 b	22.2 b
Cardinal	Leaves	4.9 a	2.4 a	6.7 c	1.6 a	1.6 a	0.5 a	111.8 a	60.0 a
	Petioles	4.1 b	1.0 cd	9.9 b	0.4 c	0.7 b	0.1 b	24.7 b	30.1 b
Sea Foam	Leaves	5.0 a	1.9 a–c	8.2 bc	1.3 ab	1.4 a	0.5 a	101.6 a	59.9 a
	Petioles	4.4 ab	0.9 d	10.3 b	0.4 c	0.8 b	0.2 b	18.5 b	34.8 ab
Bright Yellow	Leaves	4.5ab	1.4 a–d	7.6 bc	1.0 a–c	1.3 ab	0.4 ab	70.5 ab	38.8 ab
	Petioles	4.3ab	1.1 b–d	8.5 bc	0.5 bc	0.9 ab	0.3 ab	47.6 ab	31.6 ab
Silverbeet	Leaves	5.0 a	1.8 a–c	6.5 c	1.3 ab	1.4 a	0.5 a	100.9 a	50.4 a
	Petioles	4.0 b	0.8 d	8.5 bc	0.4 c	0.7 b	0.1 b	17.9 b	21.9 b
Bright Lights	Leaves	5.0 a	1.9 a–c	7.5 bc	1.3 ab	1.4 a	0.5 a	98.4 a	48.4 a
	Petioles	4.1 b	0.8 d	10.2 a	0.3 c	0.7 b	0.1 b	19.7 b	24.4 b
Significance		0.0019	<0.0001	0.0097	0.0015	<0.0001	0.0011	0.0011	<0.0001

[i] Means (n = 3) within a column followed by the same lowercase letter are not significantly different by pairwise comparison in a mixed model ($P \leq 0.05$).

shoot dry weight, root dry weight, and Swiss chard leaves (Table 1). SPAD, a measure of chlorophyll concentration, was greatest in 'Heart of Gold' and was significantly greater than any other cultivar. Chlorophyll has shown a positive correlation with β-carotene (Reif et al. 2013). 'Sea Foam' had the greatest plant width but was only significantly greater than 'Rhubarb' and 'Heart of Gold'. 'Peppermint' had the greatest number of leaves, but was not different from 'Fordhook Giant', 'Cardinal', and 'Silverbeet'. 'Bright Yellow' had the greatest shoot fresh weight and shoot dry weight, but was not different from 'Peppermint' and 'Sea Foam'. The greatest root fresh weight was found in 'Fordhook Giant', which was not different from 'Oriole', 'Peppermint', and 'Sea Foam'. 'Peppermint' had the greatest root dry weight and was greater than any other cultivar. The provitamin A content of the Swiss chard leaves was greatest in 'Fordhook Giant', but was not different from 'Peppermint', 'Rhubarb', 'Heart of Gold', 'Bright Yellow', 'Silverbeet', and 'Bright Lights'. Carotenoids in the leaf tissue are influenced by the ammonium-to-ammonia ratios (Barickman and Kopsell 2016). Although not significantly different, provitamin A petiole content varied by as much as 37% between 'Sea Foam' (the lowest amount) and 'Heart of Gold' (the greatest amount). In general, leaves had greater amounts of all nutrients, except for K, where 'Fordhook Giant' and 'Rhubarb' had greater amounts in petioles than in leaves (Table 2). Leaf and petiole nutrient levels were similar for all nutrients in 'Bright Yellow', and only total N and Zn for 'Sea Foam'. Mineral composition has been reported to be quite variable in Swiss chard accessions (Bozokalfa et al. 2011).

Conclusion

Cultivar differences were seen for SPAD, plant growth, and leaf provitamin A content. Provitamin A content was greater in petioles than in leaves for all cultivars except for 'Fordhook Giant' and 'Bright Yellow'. Greater provitamin A content and nutrient levels were not related to petiole color. In general, leaves had more nutrients than petioles, with the exception of K, whereas no differences were seen among leaves and petioles in 'Bright Yellow' for any nutrients. Future research could investigate whether color correlates with other vitamins.

References Cited

Barickman TC, Kopsell DA. 2016. Nitrogen form and ratio impact Swiss chard (*Beta vulgaris* subsp. *cicla*) shoot tissue carotenoid and chlorophyll concentrations. Sci Hortic. 204:99–105. https://doi.org/10.1016/j.scienta.2016.04.007.

Bozokalfa MK, Yağmur B, Aşçıoğul TK, Aşçıoğul YB, Eşiyok D. 2011. Diversity in nutritional composition of Swiss chard (*Beta vulgaris* subsp. L. var. *cicla*) accessions revealed by multivariate analysis. Plant Genet Res. 9(4):557–566. https://doi.org/10.1017/S1479262111000876.

du Plooy CP, Maboko MM, van den Heever E, Chiloane S. 2012. Research and technology transfer by the Agricultural Research Council to sustain the South African hydroponic industry. Acta Hortic. 947:147–151. https://doi.org/10.17660/ActaHortic.2012.947.17.

Gamba M, Raguindin PF, Asllanaj E, Merlo F, Glisic M, Minder B, Bussler W, Metzger B,

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Kern H, Muka T. 2021. Bioactive compounds and nutritional composition of Swiss chard (*Beta vulgaris* L. var. *cicla* and *flavescens*): A system review. Crit Rev Food Sci Nutr. 61(20):3465–3480. https://doi.org/10.1080/10408398.2020.1799326.

Parkell NB, Hochmuth RC, Laughlin WL. 2016. Leafy greens in hydroponics and protected culture for Florida. EDIS. 2016(3):7. https://doi.org/10.32473/edis-hs1279-2016.

Rana MK. 2016. Salad crops: Leaf-type crops. Encycl Food Health. 673–678. https://doi.org/10.1016/b978-0-12-384947-2.00603-6.

Reif C, Arrigoni E, Schärer H, Nyström L, Hurrell RF. 2013. Carotenoid database of commonly eaten Swiss vegetables and their estimated contribution to carotenoid intake. J Food Comp Anal. 29(1):64–72. https://doi.org/10.1016/j.jfca.2012.10.005.

Ross AC. 2010. Pro-vitamin A. In: Milner J, Romagnolo D (eds). Bioactive compounds and cancer: Nutrition and health. Humana Press, Totowa, NJ, USA. https://doi.org/10.1007/978-1-60761-627-6_16.

Rucker RB. 2001. Handbook of Vitamins. Marcel Dekker, NY, USA.

Sgherri C, Cecconami S, Pinzino C, Navari-Izzo F, Izzo R. 2010. Levels of antioxidants and nutraceuticals in basil grown in hydroponics and soil. Food Chem. 123(2):416–422. https://doi.org/10.1016/j.foodchem.2010.04.058.

Sommer A. 2008. Pro-vitamin A deficiency and clinical disease: An historical overview. J Nutr. 138(10):1835–1839. https://doi.org/10.1093/jn/138.10.1835.

US Department of Health and Human Services. 2023. Office of dietary supplements: Pro-vitamin A and carotenoids. NIH Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Pro-vitaminA-HealthProfessional/. [accessed 6 Apr 2025].

Zhang H, Henderson K. 2016. Procedures used by OSU Soil, Water and Forage Analytical Laboratory. PSS-2901. Oklahoma Cooperative Extension Service, Stillwater, OK, USA.

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