Globe Artichoke Production Potential in Northern New England

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ABSTRACT. Globe artichokes (*Cynara cardunculus* var. *scolymus*) are high-value crops grown primarily as perennials in locations with temperate climates, such as Italy, Spain, and central California (USA). When grown as annual crops in cooler regions such as New England, vernalization is required for first-year bud production. However, despite factoring heavily into annual production potential, chilling requirements vary by genotype and are undocumented for most commercially available cultivars. We compared the marketable yield potential of eight artichoke cultivars grown as annuals in Monmouth, ME, USA, over 3 years in replicated field experiments. We also compared black plastic culture against bare ground, straw mulch, and reflective mulch. Increasing seedling cold exposure to 550 hours before transplanting resulted in increased yields across all cultivars, and the production potential was on par with yields in other regions where artichokes are grown annually. 'Green Globe Improved' produced consistently high yields of marketable artichokes. 'Tavor' and 'Wonder' produced yields comparable to 'Green Globe Improved' but appeared sensitive to black plastic mulch in particularly hot environmental conditions. Artichokes grown on bare ground during two of three trial years were less productive than those grown on black plastic or reflective mulches, likely because of nutrient leaching. Most buds produced across all years, mulches, and cultivars were small (<3 inches in diameter). Producers in New England should ensure that their markets will be receptive to small artichokes before growing annual artichoke crops at scale.

Globe artichokes (*Cynara cardunculus* var. *scolymus*) are perennial crops grown for the edible fleshy bracts and receptacles of their immature inflorescences, or flower buds. Plants typically produce one to three large artichokes from the terminal buds of flower stalks and many smaller artichokes from axillary buds. Large artichokes contain immature florets, which are often called chokes because they are inedible. Smaller artichokes, generally processed for artichoke hearts, can be harvested before chokes develop.

Artichokes are native to the Mediterranean region where they are grown as perennials that begin producing flower buds in their second year (Ryder et al. 1983). In New England, artichokes are not sufficiently cold-hardy to reliably survive winters, and plants must be vernalized to produce buds in their first year (García and Cointry 2010; Gerakis et al. 1969; Martin 2015; Rangarajan et al. 2000). Therefore, some artichoke cultivars such as Imperial Star have been developed to produce consistently high-quality buds in annual production systems (Schrader and Mayberry 1992). Chilling requirements are fairly well-documented for Imperial Star and older commercial varieties (Welbaum 1994). This has not been formally explored for newer cultivars; therefore, current vernalization recommendations for producers in New England remain general (Sideman et al. 2023).

The simplest method of vernalizing artichokes is to transplant seedlings early enough in spring for them to accrue chilling units from ambient temperatures. Although there are few direct comparisons to more controlled vernalization methods and no vernalization temperature range has been established, this strategy has proven sufficient in temperate regions, including western Oregon (Baggett et al. 1982), Connecticut (Hill 2001; Hill and Maynard 1989), and, for 'Imperial Star' only, western Virginia (Welbaum 1994). In upstate New York, however, Rangarajan et al. (2000) found natural vernalization induced flowering less reliably with later planting dates, and that plants benefited from artificial vernalization when transplanted as late as mid-May. Field access in early spring is essential for vernalizing artichokes naturally, but field conditions in northern New England tend to be unfavorable for planting at this time. Therefore, exposing seedlings to cool temperatures before transplanting is the current recommendation for annual artichoke production in New England (Sideman et al. 2023). This treatment can effectively vernalize plants and reduce the risk of depending on ambient conditions (García and Cointry 2010; Gerakis et al. 1969; Hill 2001; Hill and Maynard 1989).

Mulching artichoke transplants with plastic or organic materials may also impact vernalization. Hill and Maynard (1989) found dramatic yield increases in plants mulched with straw in Texas and attributed this to soil cooling effects. Early research by Gerakis et al. (1969) demonstrated that artichokes may devernalize when exposed to temperatures greater than 65 °F, depending on the growth stage, but later work found that these heat units do not proportionately cancel chill units (Welbaum 1994). No other research, to our knowledge, has examined the effects of temperature, duration, cultivar, or growth stage on devernalization in globe artichoke. Because of the widespread use of black plastic mulch in diversified vegetable systems, it is especially important to assess its soil warming impact on vernalization and yield of artichokes. During Texas winter production, black plastic was found to have a positive effect on artichoke production (Leskovar et al. 2013), although artichokes were at risk for cold damage rather than heat stress. Studies that have evaluated black

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plastic mulch for artichoke culture under summer growing conditions have not been documented in the literature.

Several globe artichoke cultivars have been introduced in New England since previous cultivar evaluations (Firpo et al. 2005; Hill and Maynard 1989; McDonald et al. 2004). Therefore, the goal of this research was to update globe artichoke production recommendations for annual New England cropping systems. Our objectives were to compare the production potential of current commercially available artichoke cultivars in annual systems and evaluate the effects of mulching on marketable yields.

Materials and methods

Site description. Field experiments were conducted during the 2021, 2022, and 2023 growing seasons at Highmoor Farm, which is a University of Maine Agricultural and Forestry Experiment Station in Monmouth, ME, USA (lat. 44.231993°N, long. 70.071939°W). Soils are a Woodbridge fine sandy loam (coarse-loamy, mixed, active, mesic Aquic Dystrudepts).

Experiment details. Marketable yields were evaluated across artichoke cultivars and mulches in all field trials. In 2021, the field experiment had a split-plot replicated complete block design, with mulch as a main plot factor, cultivar as the subplot factor, and four blocks. Mulches included black plastic, bare ground, and straw. Cultivars varied by year according to availability (Table 1). In 2022 and 2023, we divided the experiment into separate cultivar and mulch trials to reduce required field space, whereby each was a single-factor randomized complete block design with four blocks. Green Globe Improved was the sole cultivar in the stand-alone mulch trials. The mulch trial treatments in 2022 and 2023 included black plastic, bare ground, and reflective mulch. Straw mulch was discontinued after 2021 because it controlled weeds poorly and hindered management. Reflective mulch was used in its place because we hypothesized that it would have a similar soil cooling effect while controlling weeds more effectively and reduce aphid pressure, which was problematic in 2021 (Brown et al. 1993).

Field culture. Each spring, 500 pounds/acre of 10–10–10 fertilizer was broadcast and incorporated after primary tillage. A bed shaper and plastic mulch layer (Model 2550; Rain-Flow Irrigation, East Earl, PA, USA) was used to create raised beds that were 3 inches tall, 30 inches wide, and approximately 6 feet apart center-to-center and covered with 1.5 mil embossed black plastic mulch. A single line of drip tape with 8-inch emitter spacings was buried 1 to 2 inches deep, slightly off center of the bed. In 2021, beds were shaped and drip tape was buried consistently, but plastic mulch was only applied over black plastic main plots. Approximately 4 inches of straw was applied by hand on appropriate main plots on 15 Jun 2021. The same was performed for both cultivar and mulch trials in 2022 and 2023, but black plastic was removed from reflective mulch and bare ground plots of mulch trials and replaced with the appropriate treatment by hand.

Artichokes were seeded into 50-cell trays (1 ⅞ in. square × 2 ⅜ in. deep cells) filled with Coast of Maine Seed Starting Mix (Portland, ME, USA) and placed on 75 °F heating mats in a greenhouse for at least 2.5 weeks or until germination plateaued (Table 2). Each year, seedlings were fertilized twice with 12–45–10 Nutriculture Spoon-Feeding Soluble Fertilizer (1 T gal^{-1} water; Plant Marvel Laboratories, Inc., Chicago Heights, IL, USA) using a Dosatron DosaCart fertilizer injector (1:64 ratio; Chico, CA, USA). Approximately 2 weeks before transplanting, when seedlings had four to six true leaves, seedling trays were watered and moved to coolers to vernalize. In 2021, trays were placed into a walk-in cooler kept at 40 °F with lights turned on approximately in sync with ambient daylight hours. In 2022, cultivar trial seedlings were placed in a programmable chest freezer (Super-Cold Freezer; Scientemp, Adrien, MI, USA), and mulch seedlings were placed in a laboratory refrigerator (model EHT201ZKWR3; Whirlpool Corporation, Benton Harbor, MI, USA) at 44 °F and 36 °F, respectively. Neither had supplemental lighting. In 2023, trays were placed in a 42 °F walk-in cooler with full-spectrum light-emitting diode (LED) lights (DIO-WATT 1152, 1000-lm. 660-WATT Full Spectrum; AgroLED, Kyiv, Ukraine). After a minimum of 12 d, trays were moved outside to a shady location to harden-off.

Seedlings were transplanted by hand within 3 days of removal from coolers (Table 2). Artichokes were spaced 24 inches apart within single rows. In 2021 and subsequent cultivar trials, all plots contained 12 plants, and data were collected from the central 10 plants. Mulch trials in 2022 and 2023 contained seven plants, each with data collected from the central five.

After transplanting, seedlings were watered with a water-soluble 20–20–20 fertilizer solution (1 T gal^{-1} water; Peter's Professional General Purpose, Dublin, OH, USA). Thereafter, drip irrigation was used to fertigate plots and ensure that plants received 1 inch of water weekly when precipitation was insufficient; the same fertilizer injection system as that used for seedling production was used. All plots were hand-weeded as necessary throughout the growing season.

Esfenvalerate (Asana® XL; Valent, San Ramon, CA, USA) and acetamiprid

Table 1. Globe artichoke cultivars evaluated in each cultivar trial year in Monmouth, ME, USA, from 2021 to 2023.

Cultivar	Years evaluated 2021	2022	2023	Seed source[i]
Colorado Star	x	x		Johnny's
Green Globe Improved	x	x	x	Osborne in 2021 and 2023; Territorial in 2022
Imperial Star	x	x	x	Fedco in 2021; Johnny's in 2022 and 2023
Imperial Star Purple		x	x	Territorial
Romanesco		x	x	Northeast
Tavor	x	x	x	High Mowing
Violetto		x	x	Territorial
Wonder	x	x	x	High Mowing

[i] Fedco = Fedco Seeds (Clinton, ME, USA); High Mowing = High Mowing Organic Seeds (Wolcott, VT, USA); Johnny's = Johnny's Selected Seeds (Albion, ME, USA); Northeast = Northeast Seed (East Hartford, CT, USA); Osborne = Osborne Quality Seeds (Mt. Vernon, WA, USA); Territorial = Territorial Seed Company (Cottage Grove, OR, USA).

Table 2. Artichoke production details for trials in Monmouth, ME, USA from 2021 to 2023.

Production operations	Year		
	2021	2022[i]	2023[i]
	Dates		
Seeding	22 Mar (−63)[ii]	23 Mar (−76)	24 Mar (−80)
Vernalization	10–24 May (−14 to 0)	24 May–6 Jun (−14 to −1)	17 May–9 Jun (−26 to −3)
Transplanting	24–26 May (0 to 2)	7 Jun (0)	12 Jun (0)
Harvest	20 Aug–1 Oct (88 to 130)	29 Aug–12 Oct (83 to 127)	14 Aug–2 Oct (63 to 112)
	Vernalization details		
Temperature (°F)	40	44/36[iii]	42
Duration (h)	336	303	550

[i] Both cultivar and mulch trials.
[ii] Number in parentheses indicates days after transplanting.
[iii] Separate temperatures for cultivar and mulch trial seedlings, respectively.

(Assail 30 SG; United Phosphorus, Kingstree, SC, USA) were applied at label rates as needed to control green peach aphid (*Myzus persicae*), stink bug (order Pentatomidae), tarnished plant bug (*Lygus lineolaris*), and thrips (order Thysanoptera). To manage gray mold (*Botrytis cinerea*), captan (Captan 4L; Drexel Chemical, Memphis, TN, USA) and boscalid plus pyraclostrobin (Pristine; BASF Corporation, Florham Park, NJ, USA) were applied at label rates. In 2023, we were unable to apply pesticides after the first month of field culture because of excessive precipitation, and losses from insects and fungal diseases were high.

Data collection. Artichokes were harvested beginning when full size was reached but buds had not yet begun to open, and then weekly or biweekly thereafter depending on production patterns (Table 2). Harvest continued until either a hard freeze or when the majority of buds became unmarketable, depending on the year. Buds were clipped from plants with 1 to 2 inches of the stem attached. Marketable buds were separated into the following US Department of Agriculture (USDA) size classes: 3 to 3.5, 3.5 to 4, 4 to 4.5, and more than 4.5 inches in diameter. These classes were combined into a "large" class, denoting that they had the potential for individual sale. All buds smaller than 3 inches in diameter were categorized into a "very small" class. Although this size is not in a USDA-designated size class, we believe these have good potential in local markets for selling by weight or volume.

All data were collected and recorded from individual plants to assess the proportion of plants that produced buds as an indication of successful vernalization. Because vernalization requirements were unknown (and remain unclear), yield data were normalized to flowering plants only, reflecting production potential. For each plant, the number and weight of marketable buds in each size class were recorded. Culled buds were counted and weighed, and the reason or reasons that rendered them unmarketable were noted. Unmarketable buds were typically a result of malformation (caused by thrip, stink bug, and tarnished plant bug feeding) or gray mold. Infrequently, insect feeding on bracts rendered buds unmarketable. In 2023, a heavy aphid infestation was present at harvest because excessive rainfall prevented pesticide applications through much of the season in this year. Therefore, buds with aphids were not marked as culls because standard pesticide applications would have addressed this; however, instead, they were recorded as marketable and noted as having aphids.

Weather. Temperature and precipitation data for the 3 years of this study were gathered from the nearest National Oceanic and Atmospheric Administration weather station in Turner, ME, USA (lat. 44.1940°N, long. 70.2647°W) (Table 3).

Statistical analysis. Data were analyzed using RStudio (R Core Team 2020). Years were analyzed separately because of variable vernalization and environmental conditions. To evaluate production potential and account for the inconsistency of vernalization treatments across years, yield data were normalized to the number of flowering plants. Where necessary, data were log-transformed to improve normality and heteroskedasticity of residuals. Linear mixed models were created using the 'lme4' package for evaluating the cultivar and mulch as fixed effects while maintaining block as a random effect (Bates et al. 2015). Treatment differences were deemed significant at $P \leq 0.05$ for type III sums of squares tests. Post hoc pairwise comparisons were made using 'emmeans' and were considered significantly different at $P \leq 0.05$ (Lenth et al. 2004).

Table 3. Temperature and precipitation data for June through September of each trial year based on the National Oceanic and Atmospheric Administration data for Turner, ME, USA.

	June				July				August				September			
	Temp (°F)			Rain (inches)	Temp (°F)			Rain (inches)	Temp (°F)			Rain (inches)	Temp (°F)			Rain (inches)
Year	Max	Min	Avg		Max	Min	Avg		Max	Min	Avg		Max	Min	Avg	
2021	92	44	68	0.94	91	47	66	7.23	91	51	70	3.37	77	42	57	0.34
2022	89	44	62	3.79	90	51	71	3.67	92	55	70	4.88	83	36	59	6.28
2023	92	41	62	5.75	90	51	71	6.63	83	48	66	7.22	88	42	63	4.47

Table 4. Mulch, cultivar, and mulch × cultivar interaction effects on yield characteristics of artichoke in 2021 in Monmouth, ME, USA.

	Flowering plants	Marketable buds per flowering plant									
		Very small (<3 inches)		Large (>3 inches)		Total marketable		Total yield per flowering plant		% Unmarketable	
Treatment	%	no.	wt (g)	no.	wt (g)	no.	wt (g)	no.	wt (g)	no.	wt (g)
Bare ground	73	8.2	464 a[i]	1.2 a	235	9.4 a	699 a	9.7	723 a	3.2	3.0
Black plastic	72	10.0	565 a	0.9 ab	180	10.9 a	745 a	11.2	765 a	1.8	2.3
Straw	56	7.2	371 a	0.7 b	155	7.9 a	526 a	8.2	546 a	3.4	3.2
Mulch *P* value[ii]	0.389	0.059	0.030	0.006	0.018	0.047	0.014	0.075	0.018	0.494	0.782
Colorado Star	76	5.9 B[iii]	365	1.0	199	6.9 B	564	7.1 B	579	2.3	2.5
Green Globe Imp.[iv]	77	12.1 A	624	0.7	125	12.8 A	749	13.2 A	772	3.0	3.0
Imperial Star	65	7.3 B	407	1.1	236	8.4 AB	643	8.8 AB	674	4.3	3.9
Tavor	62	7.8 AB	462	1.1	222	8.9 AB	684	9.2 AB	713	2.5	3.4
Wonder	55	9.2 AB	476	0.9	167	10.1 AB	643	10.3 AB	651	2.0	1.4
Cultivar *P* value[ii]	0.014	0.003	0.065	0.162	0.023	0.007	0.428	0.009	0.418	0.504	0.537
Bare ground											
Colorado Star	75	6.5	410	1.0	236 AB	7.6	646	7.8	656	2.3	1.6
Green Globe Imp.	89	10.9	551	0.7	128 B	11.6	679	12.1	710	4.3	4.4
Imperial Star	61	6.8	397	1.0	218 AB	7.9	615	8.6	662	6.9	5.4
Tavor	78	8.5	488	1.5	310 Aa	10.0	799	10.2	829	2.3	3.5
Wonder	62	8.4	474	1.5	281 ABa	9.9	756	9.9	757	0.3	0.1
Black plastic											
Colorado Star	96 A	6.9	447	1.2	233	8.0	679	8.3	705	2.8	3.5
Green Globe Imp.	91 A	12.2	627	0.7	151	12.9	778	13.1	785	1.2	0.9
Imperial Star	66 AB	8.7	523	1.2	242	9.9	766	10.1	789	1.5	2.5
Tavor	53 B	8.3	567	0.7	119 b	9.0	687	9.3	720	2.0	3.5
Wonder	53 B	14.0	661	0.8	154 ab	14.8	815	15.1	827	1.5	1.3
Straw											
Colorado Star	57	4.4	239	0.6	128 AB	5.0	367	5.1	378	1.9	2.3
Green Globe Imp.	51	13.2	693	0.6	97 AB	13.7	791	14.2	819	3.6	3.8
Imperial Star	66	6.4	301	1.0	247 A	7.3	549	7.8	573	4.4	3.8
Tavor	56	6.6	331	1.0	235 ABab	7.6	566	8.0	591	3.2	3.3
Wonder	50	5.3	291	0.3	66 Bb	5.7	815	6.0	370	4.1	2.8
Interaction *P* value	0.046	0.406	0.730	0.100	0.036	0.364	0.469	0.414	0.550	0.543	0.830

[i] Mulch values followed by the same lowercase letters within a column are not different according to Tukey's honestly significant difference ($P > 0.05$).
[ii] When interaction effects are significant, pairwise comparisons of main effects are not shown.
[iii] Cultivar values followed by the same capital letters within a column are not different according to Tukey's honestly significant difference ($P > 0.05$).
[iv] Cultivar Green Globe Improved.

Results

Temperature and precipitation varied among the three trial years (Table 3). Notably, the early growing season in 2021 was very hot and dry. In 2023, rainfall exceeded 24 inches from May to September, which was approximately 20% higher than average.

In 2021, mulch, cultivar, and mulch × cultivar interaction effects on artichoke production were inconsistent across yield characteristics (Table 4). More than 90% of 'Colorado Star' and 'Green Globe Improved' plants produced buds when grown on black plastic compared with only 53% of 'Tavor' and 'Wonder' plants. No differences in flowering rates among cultivars were found in plants grown on bare ground or with straw mulch. 'Green Globe Improved' produced a greater marketable and total number of artichokes than 'Colorado Star'. This was primarily influenced by small bud yield, which 'Green Globe Improved' produced more of than both 'Colorado Star' and 'Imperial Star'. Plants grown on bare ground produced 1.2 large buds each, which was more than that grown on straw mulch, which produced 0.7 large buds each ($P = 0.034$). Yield by weight was affected only in the large bud size class, where there was a significant interaction effect. 'Tavor' and 'Wonder' produced greater large bud weights on bare ground than on black plastic and straw, respectively ($P \leq 0.009$). On bare ground, 'Tavor' produced more than double the large buds by weight than did 'Green Globe Improved' ($P = 0.039$). On straw mulch, 'Imperial Star' produced approximately four-times more large buds by weight than 'Wonder' ($P = 0.042$). High variability within mulch treatments resulted in few other statistically different pairwise comparisons between them despite several significant main effects. The majority of culled buds displayed symptoms of gray mold infection (data not shown). Unmarketable buds accounted for a very small proportion of total yield in 2021, ranging only from 2.0% to 4.3% across cultivars, and was unaffected by mulch or cultivar.

Artichoke production in 2022 was variable and poor (Table 5). Only 3% to 33% of plants produced buds ('Wonder' and 'Colorado Star', respectively), although no statistical difference in flowering among cultivars was detected because of high variability ($P = 0.09$). Total yields ranged from 1.0 ('Imperial

Table 5. Mulch and cultivar effects on yield characteristics of artichoke in 2022 in Monmouth, ME, USA.

		Marketable buds per flowering plant									
	Flowering plants	Very small (<3 inches)		Large (>3 inches)		Total marketable		Total yield per flowering plant		% Unmarketable	
Treatment	%	no.	wt (g)	no.	wt (g)	no.	wt (g)	no.	wt (g)	no.	wt (g)
Colorado Star	33	5.6	536	1.9	346	7.4	882	7.5	893	0.7	0.9
Green Globe Improved	20	4.8	344	1.3	228	6.1	572	6.1	572	0	0
Imperial Star	25	3.1	313	1.4	306	4.4	619	4.5	630	1.1	1.2
Imperial Star Purple	15	0.4	30	0.6	144	1.0	173	1.0	184	1.7	2.5
Romanesco	27	3.6	263	1.9	252	5.5	514	5.5	514	0	0
Tavor	10	1.3	95	0.7	135	1.9	229	1.9	229	0	0
Violetto	5	3.5	267	1.3	270	4.8	536	4.8	536	0	0
Wonder	3	2.0	189	0.3	72	2.3	261	2.3	261	0	0
P value	0.090	0.248	0.186	0.259	0.570	0.190	0.234	0.194	0.236	0.628	0.605
Bare ground	30	1.8 b[i]	141 a	1.3	222	3.0 a	363	3.0 a	363	0	0
Black plastic	5	13.0 a	644 a	1.0	158	14.0 a	802	14.0 a	802	0	0
Reflective	20	8.2 a	513 a	2.2	342	10.3 a	854	10.5 a	870	2.6	2.4
P value	0.064	0.020	0.021	0.616	0.695	0.043	0.134	0.037	0.115	—[ii]	—

[i] Values followed by the same letters within a column are not different according to Tukey's honestly significant difference ($P > 0.05$).
[ii] Indicates data not analyzed because of low occurrence.

Star Purple') to 7.5 ('Colorado Star') buds per flowering plant, and from 184 to 893 g for the same cultivars. Despite more than this four-fold difference, production was too variable to detect significant cultivar differences. Although the overall proportion of plants that produced buds was low, the high end of the yield range was on par with other years of this study when measured on a per flowering plant basis. The proportion of plants that flowered in the mulch trial had a range similar to those in the cultivar trial and, similarly, was too variable to detect statistical differences ($P = 0.064$). Plants grown on bare ground produced fewer small buds than those grown on black plastic and reflective mulches ($P = 0.031$ and 0.035, respectively). The number of total and marketable buds produced was also far greater in plants grown on black and reflective mulches, but pairwise comparisons were not significant. Few buds were deemed unmarketable in 2022, with no difference among cultivars, and only one unmarketable artichoke in the mulch trial precluded statistical analysis.

Artichoke production was greatest in 2023, when rainfall far exceeded that of other years. Vernalization was also more successful than that in previous years, except for Violetto, which flowered at a lower rate (68%) than that of all other cultivars (97% on average) (Table 6). Mulch had no impact on flowering rates ($P = 0.662$). 'Tavor' was most productive across size classes; along with 'Green Globe Improved', 'Romanesco', and 'Wonder', it produced more very small and total marketable buds than 'Violetto'. 'Tavor' and 'Imperial Star' produced approximately three-times more large buds than did 'Romanesco'. By weight, Tavor and Wonder produced a greater yield of small buds than Violetto and total marketable buds than those of purple cultivars Imperial Star Purple and Violetto. 'Tavor' produced 153 g

Table 6. Mulch and cultivar effects on yield characteristics of artichoke in 2023 in Monmouth, ME, USA.

		Marketable buds per flowering plant									
	Flowering plants	Very small (<3 inches)		Large (>3 inches)		Total marketable		Total yield per flowering plant		% Unmarketable	
Treatment	%	no.	wt (g)	no.	wt (g)	no.	wt (g)	no.	wt (g)	no.	wt (g)
Green Globe Improved	100 a[i]	12.5 a	526 ab	0.4 ab	69 ab	12.9 a	595 ab	16.6 a	702 ab	22.1 c	15.3 bc
Imperial Star	100 a	9.5 ab	430 ab	0.8 a	136 ab	10.3 ab	566 ab	18.7 a	804 a	44.7 a	29.7 a
Imperial Star Purple	92 a	9.0 ab	372 ab	0.4 ab	68 ab	9.5 ab	440 b	15.0 a	589 ab	37.8 ab	26.0 ab
Romanesco	88 a	12.2 a	510 ab	0.3 b	42 b	12.5 a	552 ab	14.7 a	618 ab	15.2 c	10.7 c
Tavor	100 a	13.0 a	548 a	0.9 a	153 a	13.9 a	702 a	17.9 a	826 a	22.2 c	15.2 bc
Violetto	68 b	6.1 b	346 b	0.6 ab	91 ab	6.7 b	437 b	7.7 b	489 b	13.0 c	10.5 c
Wonder	97 a	12.0 a	555 a	0.7 ab	129 ab	12.7 a	683 a	16.4 a	795 a	23.1 bc	13.8 bc
P value	<0.001	<0.001	0.008	0.009	0.022	<0.001	0.003	<0.001	0.001	<0.001	<0.001
Bare ground	95	9.2	370	0.5	71	9.7	441	13.8 b	550	29.7	19.1
Black plastic	100	12.2	559	0.8	131	13.0	690	17.3 ab	799	24.8	13.7
Reflective	95	16.6	679	0.4	60	17.0	738	24.1 a	921	31.7	22.3
P value	0.662	0.065	0.078	0.223	0.204	0.079	0.112	0.020	0.077	0.461	0.209

[i] Values followed by the same letters within a column are not different according to Tukey's honestly significant difference ($P > 0.05$).

of large buds, which was more than three-times that produced by 'Romanesco' (42 g of large buds) (P = 0.037). Compared to all other cultivars evaluated, Violetto produced fewer total buds. By weight, 'Imperial Star', 'Tavor', and 'Wonder' produced greater total yields than that of 'Violetto'. The discrepancy between cultivars producing the highest marketable and total yields was attributable to an overall high proportion of unmarketable artichokes in this year, which was upward of 13% of buds, depending on the cultivar. Gray mold was the primary reason for culling buds, which was likely exacerbated by frequent rainfall in this year (Table 3), and insect feeding was also prevalent (data not shown). Imperial Star had a greater rate of cull artichokes by weight (44.7%) and number (29.7%) compared to those of all other cultivars except Imperial Star Purple. Heirloom cultivars Romanesco and Violetto had the lowest rates of unmarketable artichokes by weight (10.7% and 10.5%, respectively). The proportion of buds by weight that were unmarketable produced by 'Green Globe Improved', 'Tavor', and 'Wonder' were also relatively low (<16%). Mulch had a less definite effect on artichoke yields. Although plants on reflective mulch produced almost double the very small and total marketable yields of those grown on bare ground, these differences were not significant (P = 0.065 and 0.079, respectively). However, the total number of artichokes produced was greater in reflective mulch than in bare ground (P = 0.031), whereas that of plants grown on black plastic was intermediate and did not differ from either. Cull rates and the proportion of buds with aphid infestations at the time of harvest did not differ between mulches (data not shown).

Discussion

Wide seasonal variations in temperature and precipitation affected artichoke plant performance and response to treatments over the 3 years of this study, including the effectiveness of vernalization and resultant frequency flower bud development. Vernalization strategies and their efficacy had an overriding effect on artichoke production; the proportion of plants that produced buds ranged from 3% to 100% across 3 years and eight cultivars. Flowering occurred more reliably in years when seedlings were subjected to longer cold durations. This has been previously documented, where two to four weeks of vernalization duration resulted in a greater percentage of flowering plants than those exposed to only one week (Gerakis et al. 1969). In this study, production was dramatically improved when plants were vernalized for at least 2 weeks (336 h) in temperatures at or below 40 °F (Table 2). In 2022, plants were vernalized for only 12.6 d. Although cultivar and mulch trials were vernalized at 44 °F and 36 °F, respectively, flowering ranges did not vary between trials, suggesting that the duration of cold exposure is more important than temperature. Similarly, Gerakis et al. (1969) found that plants vernalized at 45 °F for 4 weeks flowered at the same rate as that of those vernalized at 40 °F and 35 °F, and the rate was only greater than that of those vernalized at 32 °F. In combination, these results suggest that duration is a key driver of vernalization success when temperatures are at least 35 °F. A high temperature threshold remains unclear, although 50 °F is frequently cited (Hill 2001; Sideman et al. 2023). Rangarajan et al. (2000) measured increased flowering rates with 19 d at 55 °F and compared them with that of a control without vernalization.

Devernalization in artichoke is not well-understood. Gerakis et al. (1969) reported a devernalizing effect that resulted from temperatures exceeding 65 °F at the time of sowing vernalized seed; however, in 80-d-old seedlings, exposure to temperatures up to 120 °F did not induce devernalization. In this study, 'Tavor' and 'Wonder' plants grown on black plastic mulch appeared to devernalize in 2021 (Table 4). Flowering was also relatively low in these cultivars in 2022, when grown on black plastic, as well as in Violetto, which had the lowest flowering rate of all cultivars in 2023. Of the three trial years, 2022 had the hottest July and August months, and these cultivars were likely more sensitive to higher temperatures (Table 3). In 2023, vernalization was more than 200 h longer than in other years, which may account for the higher flowering rates in nearly all cultivars despite high ambient temperatures throughout much of the field season (Tables 2, 3, and 6). Based on these results, vernalizing seedlings for approximately 3 weeks at 35 °F to 50 °F should provide sufficient chill hours for reliable flowering rates.

Mulching appeared to have an indirect effect on artichoke production. Black plastic mulch is known to increase soil temperature by up to 3.4 °F (Ham et al. 1993). Although reflective mulches are often cited as having a soil cooling effect (Lament 1993), they have been found to produce divergent effects (0.7 °F cooler to 3.9 °F warmer) depending on their manufacturing (Ham et al. 1993). This likely explains the similar artichoke response to black and reflective mulches in this study. Yields tended to be greater in plants grown on these mulches compared with those grown on bare ground, although yield increases were not always significant, similar to results of a Texas experiment (Leskovar et al. 2013). It is likely that these water-impermeable mulches protected soil nutrients in the crop root zone from leaching, especially in 2023, when precipitation exceeded 24 inches over 4 months (Locascio et al. 1985). Combined soil warming and leaching deterrent properties of both mulches were likely primary drivers of improved production; while others have observed reduced insect damage when using reflective mulch (Greer and Dole 2003; Hutton and Handley 2007), this was not observed in the present study (data not shown). Although devernalization appeared to occur in standard black plastic treatments in 2021, sufficient vernalization seemed to mitigate this effect in other years when plasticulture treatments produced equivalent or greater yields than those of bare ground. Because reflective mulch produced no observable yield benefits over black plastic, the latter will be the most cost-effective and productive approach for artichoke culture.

Artichoke yields varied drastically by year. Of the cultivars included in this evaluation, yields have been documented in the literature only for Green Globe Improved and Imperial Star. Results from this study demonstrate that with sufficient vernalization, Green Globe Improved, Tavor, and Wonder can be expected to produce good yields in New England, whereas purple cultivars Colorado Star and Violetto are likely to produce low yields. Yield on a per flowering plant basis matched or exceeded yields observed in low-yielding counties in California (Mayberry and Meister 2003), but they fell far short of consistently good California yields (Smith et al. 2008). It should be

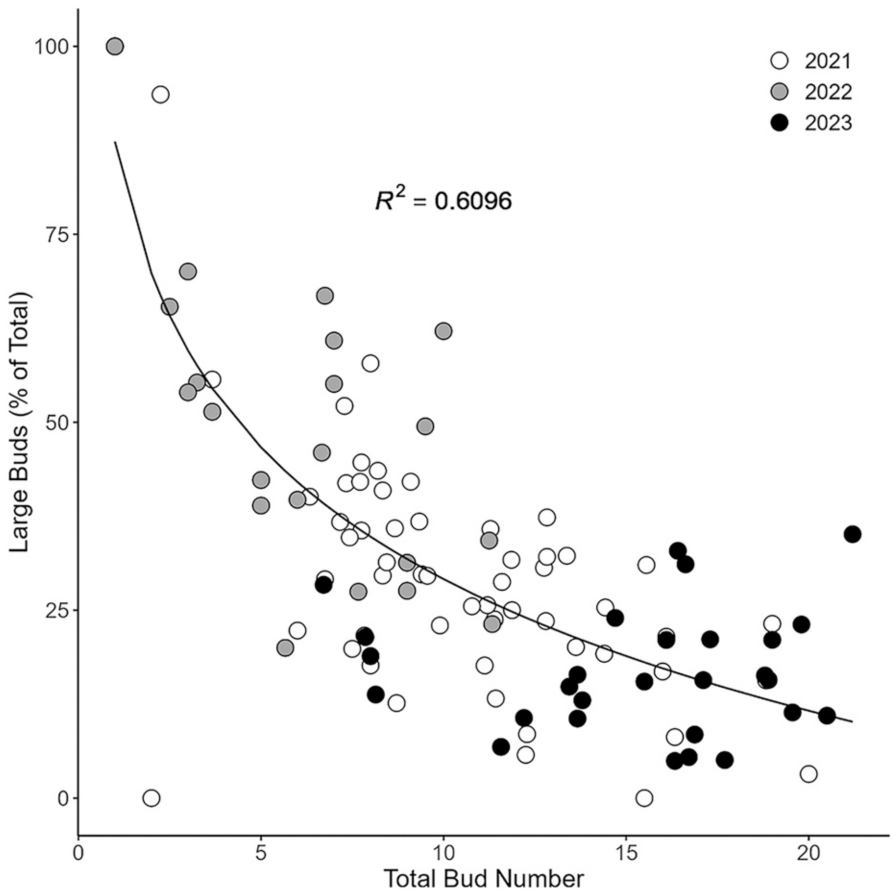

Fig. 1. Negative relationship between bud abundance and size over three annual globe artichoke field experiments in Monmouth, ME, USA.

noted that in perennial artichoke systems, harvest can occur year-round, accounting, in part, for very high yields. Plants are also regularly stumped to encourage growth of new flowering stalks that will produce large primary buds. In contrast, bud production during 2 years of this study met or exceeded documented yield ranges for 'Green Globe Improved' and 'Imperial Star' in annual Texas winter production systems (Leskovar et al. 2013; Shinohara et al. 2011). However, no minimum artichoke size was imposed in the present study, and yields were largely comprised of very small buds that would not have been considered marketable in other studies. There is a negative relationship between plant productivity and the proportion of large, individually marketable buds (R^2 = 0.61) (Fig. 1), as the first bud is generally the largest, with secondary, tertiary, etc. buds decreasing in size. This can be seen in 2021 yields, when, despite generating lower total yields than those in other years, large buds accounted for 30% of production across all cultivars compared with 10% and 4% in 2021 and 2023, respectively. Although others have used more stringent sizing standards than those in this evaluation (Hill 2001; Rangarajan et al. 2000), it may be possible to successfully market these very small artichokes in Maine, where artichokes are typically sold directly to consumers. A recent survey of nearly 1000 Maine and Vermont residents found that 25.8% of respondents participated in food preservation during the early COVID-19 pandemic (Niles et al. 2024), demonstrating that there may be a market for small artichokes for frozen and/or canned hearts. Sustained artichoke production in Maine and likely much of New England will require this type of marketing approach to fully utilize artichoke crop yields. We conclude that globe artichokes have potential as an annual specialty crop in northern New England. This study has shown that careful attention to vernalization of transplants, cultivar selection, and mulches can have significant impacts on the yield and quality of artichokes grown in this region.

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