Research paper

Exploring the~~s~~ potential of hop as a dual purpose crop in the Mediterranean environment: ~~S~~shoot and cone yield ~~as related to earliness of shoot emergence and cone yield~~ from nine commercial cultivars

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Abstract

In hopyard management, surplus shoots are generally considered a useless by-product once hop bine training has been completed. Considering the rising interest towards healthy and traditional foods, they may be a valuable resource, especially for small scale hop farming. Despite this economic and nutritional interest, there is a lack of information about hop shoot yield potential both in the heartlands and new growing areas such as the Mediterranean basin. A 2-year field trial was conducted in Central Italy to investigate the shoot yield potential of nine commercial hop cultivars and how this yield is related to other traits such as earliness of shoot emergence and shoot number and weight. Cone yield potential was also assessed. The results showed that there was significant variability among the genotypes for all characters investigated. Cascade was the highest yielding variety producing 470 g of cones per plant (two-year mean) at 10% moisture. The number of shoots per plant varied from 14 of H. Aroma to 29 of Cascade over a two year average, while green shoot~~s~~ yield ranged from 15 g per plant of H. Aroma in 2014 to 37.5 g per plant of Cascade in 2013. Marketable shoot yield was positively correlated with number of shoots, while no significant correlation was found with average shoot weight.

Since the number of shoots was negatively correlated with growing degree days (GDD) to shoot emergence, the early emerging genotypes such as Cascade, Yeoman and H. Magnum outperformed the other cultivars when grown in the Mediterranean environment for shoot production.

Keywords: Hop; Shoot yield; Cone yield; GDD accumulation; Shoot emergence; Rootstock dormancy

1 Introduction

Hop (*Humulus lupulus* L.) is a dioecious perennial climbing plant mainly cultivated for its female inflorescence (known as cone but formally strobilus), rich in alpha acids and other secondary metabolites.

Commercial production of hop is generally limited to regions between 35° and 50° latitude in both hemispheres, as the plant has specific chilling and day-length requirements for optimal growth and flowering (Haunold, 1981; Mahaffee and Pethybridge, 2009; Turner et al., 2011). Germany, U.S.A. and China are the top producers of hop in the world, but the production of all European countries is from 50 to about 62% of world production (European Commission: Agriculture and rural development, 2017).

Even though hop is mainly known as a brewing ingredient, it has been used over time for various medicinal, household and culinary purposes (Small and Catling, 1999). An ancient use concerns the harvest of wild young spring shoots to be eaten like asparagus. It seems that this dietary habit was already known by the Romans as Pliny the Elder (23~~–79 A.D~~–79 C.E.), in Book 21, Chapter 50 of his *Naturalis Historia*, possibly refers to the wild hop plant when he mentions the *lupum salictarium* (“willow wolf”) as a toothsome rather than a nourishing food.

In England, the young green shoots are eaten but it is not a common dish~~;~~ while, in Belgium, hop shoots are regarded as a delicacy (Neve, 1991). In the Mediterranean region the use of wild hop as a vegetable is quite popular, and its shoots are cooked according to traditional recipes (di Tizio et al., 2012; Hadjichambis et al., 2008; Tardio et al., 2006). After boiling, young shoots have very low lipid content (<~~-~~0.2 g/100 g), energy value (25 kcal/100 g) and Na content (~~<~~≤40 g/100 g), whereas they are a good source of dietary fibre and vitamin B_9 and C (García Herrera, 2014; Morales Gómez, 2011; Sanchez-Mata et al., 2012).

Given the renewed attention towards the recovery of food traditions and the demand for a healthy diet, wild species should be better exploited and promoted (Sanchez-Mata et al., 2012). This is particularly true in those countries where food consumption is not increasing and differentiation represents a key factor for marketing (D’Antuono et al., 2009). Moreover, the domestication and cultivation of wild plants traditionally used for food, may represent a successful strategy for niche markets (Benincasa et al., 2007; D’Antuono and Lovato, 2003; Molina et al., 2016).

Despite this economic and nutritional interest, there is still little knowledge about yield potentials of wild edible plants, particularly in the Mediterranean region (Molina et al., 2014).

Hop shoots are produced from the buds of the rootstock in early spring. In grown hop plants, most of these shoots are removed by pruning, while just a few shoots (from three to six) are trained up strings for cone production (De Keukelerie et al., 1999). For brewers, the surplus shoots are a useless by-product of the supply chain, but for gastronomes, they can be one of the most valuable vegetables in the world ~~(The Guardian, 2015)~~. Their extraordinary value is based on the limited availability (just few days) and the laborious harvest.

Recently, the proliferation of microbreweries has led to a growing interest in agricultural beers and, consequentially, in hop cultivation, also in countries which are not typical producers such as Italy. In these new growing areas, very limited knowledge is available on hop phenology and feasibility of cultivation. Furthermore, while many studies have been conducted to investigate factors affecting cone yield and quality (Beatson et al., 2003; Čeh, 2014; Fandino et al., 2015; Mongelli et al., 2015; Rossini et al., 2016), no information is available on shoot production.

The use of young shoots as vegetables, on the other hand, may be a valuable additional source of income for hop growers.

This study aims to increase our understanding of the potential of cultivated hop in the Mediterranean environment, by verifying the following hypotheses:

1) There is a genotypic variability among hop cultivars for shoots yield as previously found for cones (Rossini et al., 2016);

2) As for asparagus (*Asparagus officinalis* L.), the number of shoots is positively ~~corr~~related to marketable yield (Caruso et al., 2012; Moon, 1976) and negatively to earliness of shoot emergence (Cravero et al., 2002);

3) Since the number of shoots before training is a predictor of plant vigour (Skinner et al., 1975), varieties with a high number of shoots have also high cone yield.

Such results would provide hop growers with important information for the supplemental production of shoots and would be of use in the selection of dual purpose cultivars in the Mediterranean region.

2 Materials and methods

2.1 Location, experimental design and hopyard management

The experiment was carried out during two consecutive years, 2013 and 2014, at the experimental farm of the University of Tuscia, Central Italy (42°26′ N, 12° 04′ E, altitude 310 m a.s.l.).

The growing area is characterized by a Mediterranean climate, with mean annual air temperature of about 14.5 °C and precipitation of 790 mm (Insert the Fig. 1 citation here).

The experimental design was a randomized complete block with three replicates; treatments were varieties. The hopyard was constructed in the spring of 2011 using a standard high trellis system with a finished height of 8 m. Aircraft cable was used for trellis wires. The soil was tilled with a moldboard plow, tilled again with a rotary tiller, and then planted with two hop rhizomes per hill (hereafter referred to as plant) on April 13th, 2011. Plants were distanced 1.5 m apart, and rows were spaced at 1.8 m. Each plot consisted of five consecutive plants. A rate of 150 kg ha^{-1} of K_2O was applied before soil tillage and 80 kg ha^{-1} of P_2O_5 at planting time, while N was yearly split in two rates of 50 and 50 kg ha^{-1} for spring (April) and late spring (May-June) applications. The hopyard was irrigated when needed with a drip irrigation system. The total water amount was 200 mm in 2013 and 55 mm in 2014.

Starting at the end of February 2013, hop crowns and early shoots were pruned every year to encourage a stronger secondary shoot growth and to reduce disease incidence (Turner et al., 2011).

Each year, rows were trained with two plastic strings per plant, with three to four of the most vigorous bines trained per string.

Weeds, pests and pathogens were chemically controlled to avoid any biological stress. (Please, put the figure 1 here or within this paragraph (2.1).)

2.2 Plant materials

Female plants of nine cultivars were used. The varieties were selected from a wider list to include an ample range of earliness and brewing quality traits.

Their origin, indicative harvest time and brewing use are reported in Table 1.

Table 1 List of hop cultivars used for the experiment, their harvest time, brewing use and origin.

alt-text: Table 1

Cultivar	Harvest time	Brewing Use	Origin
Cascade	M	Dual purpose	US
Fuggle	E to M	Aroma	UK
Hallertauer Aroma	E	Aroma	New Zeeland
Hallertauer Bitter	E to M	Bittering	Germany
Hallertauer Magnum	L	Bittering	Germany
HersbruckerSpät	L	Aroma	Germany
Perle	M to L	Dual purpose	Germany
Tettnanger	E	Aroma	Germany
Yeoman	E	Bittering	UK

Harvest time: E = early; M = medium; L = late.

2.3 Monitoring of shoot emergence and growing degree days (GDD) calculation

Monitoring of shoot emergence was performed daily starting from the first week of March. The BBCH centesimal scale for hop (Rossbauer et al., 1995) was used to detect the sprouting growth stage (GS: 0) and shoot emergence was reported when first shoots emerged at the soil surface (GS: 09). Daily climatic data for GDD calculation came from the University's weather station, located a few hundred metres from the experimental field.

GDD accumulation was calculated from daily air temperature according to the following formula:

$$\mathrm{GDD} = \Sigma_{days}\left(\frac{T_{\max}+T_{\min}}{2}\right) - T_{base}$$

Where T_{max} is the daily maximum temperature, T_{min} is the daily minimum temperature, T_{base} is the temperature below which the plant growth does not progress (McMaster and Wilhelm, 1997). In the present study the T_{base} used for GDD calculation was 6.5 °C and degree days were summed beginning either 1st February or after the last cold period since 1st February (Johnson, 1991). Cold period was defined as five or more consecutive days each with a degree-day value less than or equal to zero and such that if the cold period contained only 5 days, the mean of the degree-day values was also less than or equal to −2 °C.

2.4 Field measurements

Shoots of all cultivars were harvested on the same date (May 9th 2013 and May 6th 2014), after the completion of bine training. At harvest time, young shoots generally had 5 or 6 nodes completely differentiated and they were from 20 to 40 cm in length. To avoid border effects, only shoots from the three central rootstocks in each plot were used to assess yield per plant (number of shoots and their fresh and dry weight).

Fresh shoots from each plot were counted, labelled, cut at the marketable length of 20 cm and weighed. Then, to determine dry matter yield, the samples were oven-dried at 55 °C until constant weight.

Average fresh shoot weight was determined by dividing the total fresh weight of shoots by their number.

Cone harvest was performed at ripeness stage (GS: 89): cone closed, lupulin golden, aroma potential fully developed (Rossbauer et al., 1995).

At harvest, hop bines were cut in the field and brought to a secondary location to be manually processed. As for shoots, only the three central plants of each plot were harvested for cone yield determination (Fandino et al., 2015; Kappagantu et al., 2017).

Harvest date varied from July 24th to September 24th in 2013 and from August 26th to September 29th in 2014, according to the cone ripeness of each cultivar.

Picked cones were weighed on a per plant basis and then oven-dried at 55 °C until 10% moisture content (marketable moisture).

2.5 Statistical analysis

Data was subjected to the analysis of variance (ANOVA) using R 2.4.0 software in order to test the main effects of year, cultivar and their interaction. Significantly different means were separated at the 0.05 probability level by the Fisher's least significant differences test.

Simple linear regression analysis was carried out to investigate the relationship between number of shoots and the other variables (e.g. shoot yield, fresh shoot weight and GDD to shoot emergence).

3 Results

3.1 GDD to shoot emergence

A significant cultivar × year interaction was found for earliness of shoot emergence (Table 2). Particularly, all cultivars needed a significantly higher GDD accumulation in 2014 than 2013 (Table 2). With the exception of Yeoman, date of emergence was delayed in 2014 as compared to 2013 with a range of variation from just two days for H. Magnum to twenty days for Fuggle. This latter showed the most erratic behaviour for the breaking of dormancy, it was recorded as an early sprouting cultivar in 2013 (79 GDD) and as a medium-late one in 2014 (301 GDD).

Table 2 Date of shoot emergence with relative GDD accumulation, number of shoots before training, average shoot weight (FW), marketable shoot yield (FW), shoot DM yield, cone yield at harvest (FW) and marketable cone yield (90% DM). Year × cultivar interaction.

alt-text: Table 2

Year	Cultivar	Date of shoot emergence§	GDDs to shoot emergence	Emerged shoots (no. plant $^{-1}$)	Shoot FW (g)	Shoot yield FW (g plant $^{-1}$)	Shoot yield (g DM plant $^{-1}$)	Cone yield FW (g plant $^{-1}$)	Cone yield DM (g plant $^{-1}$)
2013	Cascade	March 25th	65.59	30.33	1.24	37.53	6.72	842.57	248.87
	Fuggle	March 29th	79.06	17.00	1.07	17.52	3.12	188.43	55.80
	H. Spat	April 6th	116.57	20.00	1.07	21.03	3.78	202.20	69.96
	H. Magnum	March 29th	72.85	25.33	0.93	23.51	4.26	193.47	65.57
	H. Aroma	April 8th	123.11	14.00	1.55	21.33	3.81	162.91	46.02
	H. Bitter	April 12th	149.52	15.00	1.50	22.01	3.95	280.93	96.27
	Perle	April 15th	176.24	20.33	1.02	20.52	3.68	186.33	54.36
	Tettnager	April 10th	133.44	17.00	0.97	16.33	2.95	102.53	28.14
	Yeoman	April 5th	111.44	25.33	1.00	25.31	4.54	812.40	298.40
2014	Cascade	March 28th	172.92	27.00	1.37	36.75	6.62	1965.23	691.20
	Fuggle	April 18th	301.01	16.67	1.10	18.16	3.24	402.67	123.87
	H. Spat	April 23th	324.94	21.33	1.05	22.01	3.94	1037.36	260.43
	H. Magnum	March 31th	187.20	21.33	1.06	22.34	4.01	1133.00	358.98
	H. Aroma	April 14th	285.24	13.67	1.10	15.03	2.68	171.01	27.69

	H. Bitter	April 23th	330.92	15.33	1.45	22.22	4.00	485.40	94.03
	Perle	April 29th	381.22	19.33	1.05	20.12	3.60	95.92	33.16
	Tettnager	April 23th	333.61	12.67	1.27	15.99	2.87	523.06	140.23
	Yeoman	April 2nd	196.94	23.33	1.04	24.32	4.36	1107.97	352.61
ANOVA signif.			***	ns	*	***	***	***	***
LSD (P < 0.05)			5.25	–	0.26	1.72	0.30	97.12	24.78

§ Date of shoot emergence is averaged over plots; ANOVA signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; ns: not significant

On the other hand, Cascade, H. Magnum and Yeoman were consistently recorded as early sprouting varieties in both years, while Perle, H. Bitter and Tettnager as the late ones.

The difference between the earliest and latest cultivar (Cascade and Perle, respectively) was about 111 GDD (20 days) in 2013 and 208 GDD (31 days) in 2014.

3.2 Shoot and cone yield

3.2.1 Shoot number, weight and yield

The number of emerged shoots was not affected by cultivar ~~x~~× year interaction, whereas the ANOVA showed significant cultivar and year effect (Table~~ 2 and 3~~s 2 and 3). In 2013, the number of shoots picked up per plant ranged from 14 of H. Aroma to 30 of Cascade, with an average of 20.5 shoots per plant (Table 3). In 2014, the average number of shoots was 19 per plant, varying from 12.7 of Tettnager to 27 of Cascade. The two year average showed, Cascade, Yeoman and H. Magnum to be the best performing cultivars producing 28.7, 24.3 and 23.3 shoots per plant, respectively. On the contrary, H. Aroma, Tettnager and H. Bitter were the lowest yielding cultivars, producing 13.8, 14.8 and 15.2 shoots per plant, respectively.

Table 3 GDD accumulation to shoot emergence, number of shoots before training, average shoot weight (FW), marketable shoot yield (FW), shoot DM yield, cone yield at harvest (FW) and marketable cone yield (90% DM). Cultivar and year mean values.

alt-text: Table 3

Treatments	GDDs to shoots emergence	Emerged shoots (no. plant^{-1})	Shoot FW (g)	Shoots yield FW (g plant^{-1})	Shoots yield DM (g plant^{-1})	Cones yield FW (g plant^{-1})	Cones yield DM (g plant^{-1})
Cultivar							
Cascade	119.25	28.67	1.31	37.14	6.67	1403.90	470.04
Fuggle	190.03	16.83	1.08	17.84	3.18	295.55	89.83
H. Spat	220.75	20.67	1.06	21.52	3.86	619.78	165.20
H. Magnum	130.03	23.33	1.00	22.92	4.14	663.24	212.28
H. Aroma	204.17	13.83	1.33	18.18	3.25	166.96	36.86
H. Bitter	240.22	15.17	1.48	22.11	3.97	383.17	95.15
Perle	278.73	19.83	1.04	20.32	3.64	141.13	43.76
Tettnager	233.52	14.83	1.12	16.16	2.91	312.80	84.19
Yeoman	154.19	24.33	1.02	24.81	4.45	960.19	325.51
ANOVA signif.	***	***	***	***	***	***	***
LSD (P < 0.05)	3.71	2.70	0.18	1.22	0.21	68.68	17.52
Year							

2013	114.20	20.48	1.15	22.79	4.09	330.20	107.04
2014	279.33	18.96	1.16	21.88	3.93	769.07	231.36
ANOVA signif.	***	*	ns	**	**	***	***

ANOVA signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1; ns: not significant.

As shown in Table 2, a significant cultivar × year interaction was found for average fresh shoot weight which ranged from 0.93 g for H. Magnum to 1.55 of H. Aroma. With the exception of H. Aroma and Tettnager, all the other cultivars showed no significant differences in average shoot weight between years. Specifically, shoot weight was 29% lower and 31% higher in 2014 than in 2013, respectively in cv. H. Aroma (1.10 g vs 1.55 g) and Tettnager (1.27 g vs 0.97 g, Table 2). Despite this, the two year average showed that (Table 3) H. Aroma was one of the top performing cultivars for this trait (1.33 g, 2-years mean) together with Cascade (1.31 g) and H. Bitter (1.48 g).

A significant cultivar × year interaction was also detected for shoot yield (Table 2).

Shoot yield was not significantly different over the two year period, except for H. Aroma, which yield was 42% higher in 2013 than in 2014 (Table 2). The top yielding varieties were Cascade (about 37 g per plant), Yeoman (about 25 g per plant) and H. Magnum (about 23 g per plant), while Tettnager and Fuggle had the lowest yields, 16 and 18 g per plant, respectively (Table 3). Shoot DM content at harvest was relatively constant between years and among varieties, ranging from 17.8% for Fuggle to 18.1% for H. Magnum both in 2013.

3.2.2 Cone yield

A significant cultivar × year interaction was found for cone yield (Table 2).

Generally, the marketable cone yield (90% DM) was significantly higher in 2014 than 2013 for all cultivars with the exception of H. Aroma, H. Bitter and Perle (Table 2). Similarly to what was shown for shoot yield (Table 3), the top performing cultivars were Cascade, Yeoman and H. Magnum (470, 325.5 and 212 g plant^{-1}, respectively), while H. Aroma and Perle performed poorly (37 and 44 g plant^{-1}, respectively). In a similar trial conducted in Alburgh, VT (USA), Darby and co-workers (Darby et al., 2014, 2013) found the yield to be half the aforesaid amount for Cascade (227 g plant^{-1} at 8% moisture, two-year mean) while they observed performance to be better by Fuggle (200 g plant^{-1} at 8% moisture, two-year mean), Perle (163 g plant^{-1} at 8% moisture, two-year mean) and Tettnager (166 g plant^{-1}, two-year mean). Finally, average marketable cone yield was almost twice higher in the 2014 three year-old plants (231 g plant^{-1}) than in the 2013 two year-old plants (107 g plant^{-1}) ~~(Fig. 1)~~.

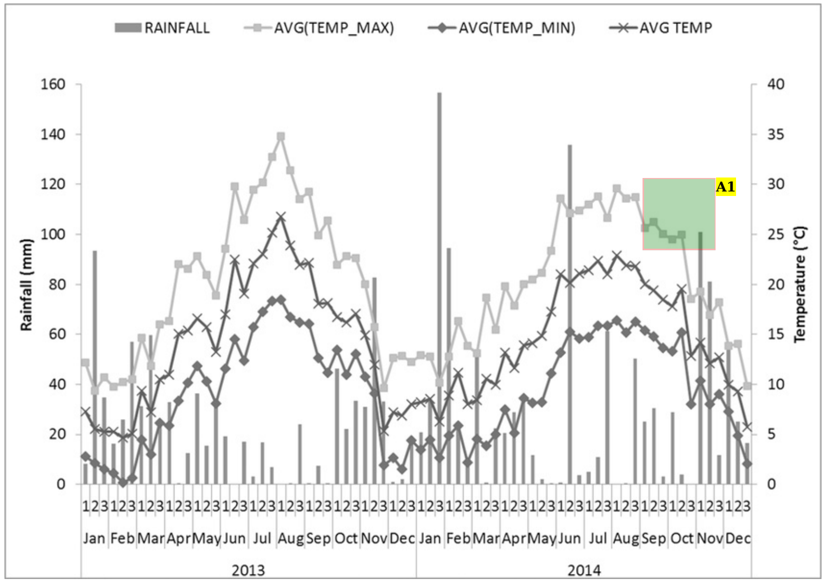

Fig. 1 Decadal mean maximum, mean minimum and average air temperature and rainfall during 2013 and 2014 growing seasons, as retrieved from the meteorological station of the experimental farm of the University of Tuscia, Viterbo (Italy).

alt-text: Fig. 1

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3.3 Relationship between number of emerged shoots, GDD and marketable yields

Fig. 2 shows the relationship between the number of emerged shoots and marketable shoot yield (A) and average fresh shoot weight and marketable shoot yield (B) in the two growing seasons.

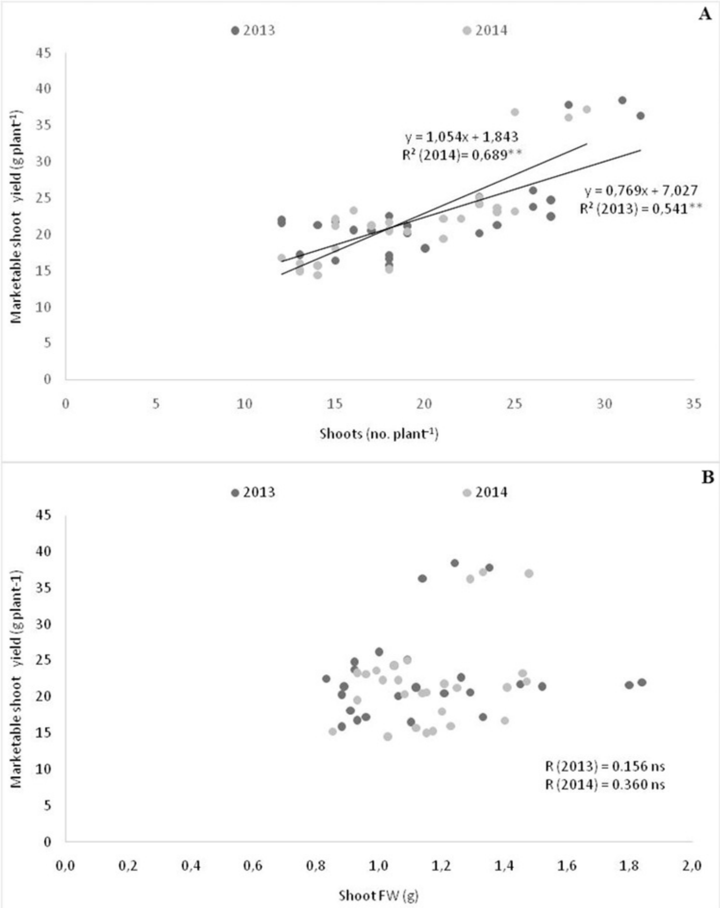

Fig. 2 Linear relationship between number of emerged shoots and marketable shoot yield (A) and between average shoot fresh weight and marketable shoot yield (B) in two growing seasons.

alt-text: Fig. 2

A significant positive relation was found between number of shoots and marketable shoot yield in both years, whereas no relation was found with the average shoot weight.

On the contrary, a significant negative relation was observed between number of shoots and GDD to shoot emergence (Fig. 3). This indicates that the early emerging varieties resprout more vigorously than medium-late ones in the Mediterranean environment,. (In the proof version, the figures 2 and 3 are placed after the Discussion section while they should be before it, like in this edit version.)

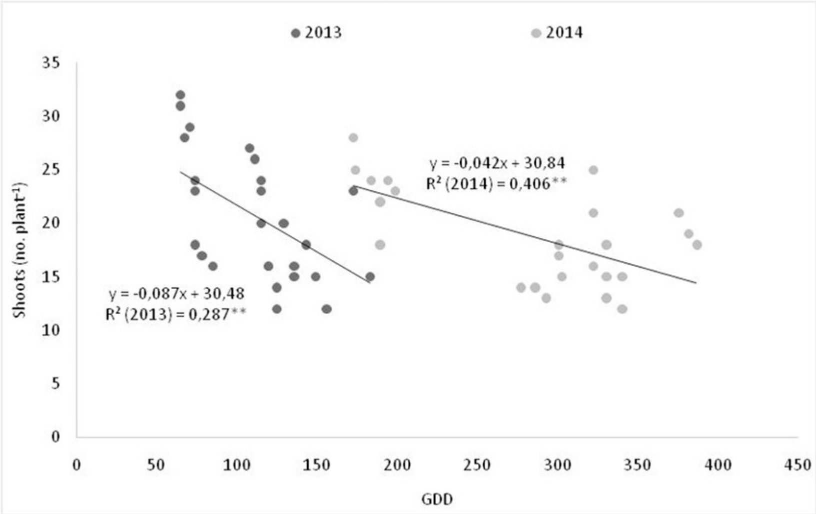

Fig. 3 Linear relationship between GDD to shoot emergence and emerged shoots in two growing seasons.

alt-text: Fig. 3

4 Discussion

The winter of 2013–2014 was dramatically warmer than that of 2012–2013. Taking into account air temperatures from December 1st to February 28th, mean temperature was 5.7 for 2012–2013 with 30 days of freezing temperatures. The mean temperature for 2013–2014 was 8.1 °C with 10 days of freezing temperatures.

Despite such a mild winter, cultivars in 2014 sprouted later or at similar dates of the previous growing season. Therefore, the shoot emergence in 2014 occurred with a GDD accumulation ~~almost~~ twice higher than in 2013 (279 vs 114 GDD). This fact could suggest that the starting time used for the total of GDD accumulation in this study was probably not correct and further research is needed to find the model that best predicts the shoot emergence. Specifically, studies in growing chambers are needed to identify both the baseline temperature for hop dormancy and chilling requirements to determine the complete vernalization. Indeed, hop plants need a certain chilling requirement to be satisfied before breaking dormancy completely. Neve (1991) reported that hop plants, which had limited exposure to low temperatures remained dormant or sprouted very erratically. These findings may explain why shoot emergence of many cultivars in our study occurred substantially later in 2014 than in 2013. A similar behaviour was found for asparagus (*Asparagus officinalis* L.), in a study conducted to investigate the effect of different chilling periods on bud break and production (Ku et al., 2008). The bud break period was longer for the asparagus plants that were not chilled than those exposed to chilling treatment. To our knowledge no studies have been conducted to identify the baseline temperature for hop dormancy, therefore no published data are available that equate chilling hours with hop shoots emergence and vegetative vigor.

Moreover, breaking of dormancy in hop may also be influenced by changes in daylength or by the interaction between temperature and photoperiod, as already found for the onset of dormancy (Neve, 1991). It was also found that high temperatures associated to a short photoperiod resulting in a low rate of sprouting buds occurred for other plants such as *Sonchus arvensis* L. (Liew et al., 2012) and many woody perennials (Olsen, 2010). This strategy prevents pre-seasonal shoot emergence and avoids frost damage in early spring, especially when mild winters occur.

Furthermore, a more precise model for the prediction of shoot emergence might be achieved by monitoring soil temperature rather than air temperature. Soil temperature 15–20 cm deep varies less during the day and affects hop rootstock more directly than does air temperature (Johnson, 1991).

As for marketable shoot yield, our study clearly demonstrated that there is a significant genotypic variability as previously found for cone yield in the same environmental conditions (Rossini et al., 2016). The yields gathered in our study (from 16 to 37 g per plant, 2-year mean) were comparable to those recorded for wild asparagus (*Asparagus acutifolius* L.), since there are no previous reports in the hop literature for this trait. Wild asparagus cultivated in Central and Southern Italy yielded from 24 to 46 g $plant^{-1}$, according to plant density and considering only spears taller than 30 cm (Benincasa et al., 2007). On the contrary, the yield per plant of wild asparagus collected in two wild Spanish sites was found to be markedly lower (from 5 to 13 g), but it has to be taken into account that in this study only the edible part of the spears (tender tip) was weighed (Molina et al., 2012).

In our study, the average weight of 20 cm shoots was lower than that found by Molina et al. (2016) in Spain (1.69 g) collecting 15~~-~~–30 cm shoots from wild plants. Moreover, the same author found the average shoot weight varying significantly according to the year of collection (Molina, 2014), while we did not. This was probably due to the fact that wild plant growth is primarily dependent upon year to year precipitation which is variable, whereas irrigated crops do not undergo any variation. However, we found total yields depending on the shoot number, rather than shoot weight. This result agrees with studies conducted on wild asparagus in Italy and Spain (Benincasa et al., 2007; Molina et al., 2012). In such environs, the reduction of spear yield was related to the decrease of spear number, whereas it was unaffected by average spear weight. As suggested by Benincasa et al. (2007) for wild asparagus, this feature might be due to the limited ability of hop to increase shoot diameter in response to rootstock abundant reserves. Therefore, increasing shoot emergence remains the only outlet for the most vigorous cultivars to spend reserves.

Moreover, the correlation between spear number and marketable yield is well known in *Asparagus officinalis* L. (Caruso et al., 2012; Moon, 1976; Poll and Van Kruistum, 1987).

The hop cultivars which produced the higher number of shoots per plant were also the top performing genotypes for cone yield (Cascade, Yeoman and H. Magnum). Since we also found a negative correlation between number of shoots and GDD to emergence, it is arguable that in the Mediterranean climatic conditions the early sprouting cultivars are those with higher yield potential. The influence of earliness on yield was already demonstrated for *A. officinalis* (Cravero et al., 2002; Ellison et al., 1960). In this species, the strong positive correlation between fern and crown weight is well known (Dufault and Greig, 1983), so that maximum yields occur when plants produce many large ferns (Ellison et al., 1960). Similarly in hop, the higher number of shoots might originate from the larger rootstocks which in turn, might derive from cultivars with higher photosynthetic activity (Pokorný et al., 2011) and then higher carbohydrate accumulation.

5 Conclusions

Hop cultivars differed significantly for all the traits investigated.

In this study, marketable shoot yield was positively correlated with number of shoots, whereas no correlation was found with average shoot weight.

Moreover, the number of shoots before training was negatively correlated with GDD to shoot emergence. These results, coupled with those on cone yield, suggest that in the Mediterranean environment the early emerging genotypes such as Cascade, Yeoman and H. Magnum were those with the highest shoot and cone yield potential.

However, a cultivar diversification strategy whereby the larger hopyards are planted to cultivars having different shoot emergence timelines, might help to prolong the shoot harvest period and better manage the timing of training and pruning.

Further studies should investigate the chemical composition of hop shoots deriving from different commercial varieties, in order to better understand their potential benefits for human health.

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Highlights

- Marketable hop shoot yield depends on the shoot number, rather than shoot weight.
- Early emerging cultivars produce a higher number of shoots per plant.
- Cascade, H. Magnum and Yeoman have potential as dual purpose cultivars.

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