Agronomic performance and beer quality assessment of twenty hop cultivars grown in Central Italy

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Abstract

Hop market and beer industry have always been of secondary relevance in Italy as compared to grape and wine sector. Hence, hop cultivars and the information for growing hops have been generated almost entirely from the major hop production countries. Identifying cultivars that perform well in Mediterranean environments is therefore essential to successfully start hop cultivation and breeding activity in this new growing region. To evaluate the intraspecific diversity of hop in Central Italy, 20 female hop genotypes with different origin were screened during three growing seasons (2013-2015) in an experimental hop yard. Cones yield, plant height and crop phenology were evaluated to determine which cultivars were best suited to the Mediterranean climate. Moreover, given the rising interest for the development of local beers with distinguishing aroma, a sensory analysis was performed and beers flavoured with locally produced and imported cones were compared. A significant diversity among cultivars was found for all parameters investigated. The results indicated that weather condition during flowering and development of cones markedly affected yield and plant height. Cones yield was negatively correlated with thermal time ($r=-0.5$, $P<0.05$) to harvest and positively with plant height ($r=0.56$, $P<0.05$). *Cascade*, *Hallertauer Magnum*, *Hersbrucker Spat* and *Yeoman* showed the best adaptability to the Mediterranean growing conditions as they were the top-performing cultivars across the three years. Sensory analysis evidenced the importance of cultivar selection as determining factor for flavouring properties of beers. In general, results showed that the origin of cones strongly affected the mouth feel of beers. More complex and appreciated aroma profiles were identified for beers flavoured with local cones than those hopped with commercial products.

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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 55° latitude in both hemispheres, as the plant is sensitive to chilling and day-length for optimal growth and flowering (Haunold, 1980; Mahaffee and Pethybridge, 2009).

Hop has a long history of utilisation in pharmaceutical industry, where it was principally used for its anti-anxiety purposes (Shishehgar *et al.*, 2012). It became also widely appreciated as a preservative and clarifying component in the beer-brewing process and even more to provide flavour, bitterness, aroma, and antimicrobial properties to beer (Zanoli and Zavatti, 2008; Mongelli *et al.*, 2015).

The genus *Humulus* native of North-temperate areas, consists of three species: *H. lupulus*, *H. japonicus* and *H. yunnanensis* (Small, 1978; Murakami *et al.*, 2006). *H. lupulus* has been classified into a number of taxonomic varieties distributed in different countries (Small, 1978): var. *lupulus* for European wild hops and cultivars, var. *cordifolius* for Japanese wild hops, and var. *neomexicanus, pubescens* and *lupuloides*, for North American hops.

Hop breeding started with clonal selections from adapted wild hops and gradually achieved remarkable results in improving yield and quality traits using European landraces (*Fuggle*, *Goldings*, UK; *Saazer*, Czech Republic; *Tettnanger*, *Spalter*, *Hallertauer Mittlefruh*, Germany), because they provide the flavours preferred by brewers (Patzak *et al.*, 2010).

For the brewing market it is possible to make a distinction between aroma hops varieties, grown primarily for their aroma properties, and alpha hops, grown mainly for their bittering effect (Zepp *et al.*, 1995; McAdam *et al*., 2014). The main compounds responsible of hop bittering are alpha acids, which are influenced by both genetic and environmental factors (Pavlovic *et al.,* 2012; Fandiño *et al*., 2015).

Many studies on hop are focused on the heritability of marketable traits controlled by quantitative trait locus genes and the characterisation of varieties by molecular DNA methods as those are more reliable and not affected by growing conditions and environmental factors in respect to metabolites profiling and chemical analysis (Patzak *et al*., 2010; McAdam *et al.*, 2014; Mongelli *et al.*, 2015). Hop breeding programs have been mostly focused on improving alpha acids content and disease resistance (Cerenak *et al.*, 2009; Henning *et al*., 2011), while public hop research is lacking in many aspects of basic agronomy (Turner *et al*., 2011). Besides, there are very little information about hop modern varieties cultivation and their agronomical performances and requirements, especially in Mediterranean environs (Mongelli *et al.*, 2015). Within this context, it has to be noticed that, even though wild hop plants normally grow in the whole Italian peninsula (Pignatti, 1982), no systematic studies on environmental adaptability of hop cultivars were conducted in Italy till now. This was probably due to some objective difficulties in conducting open field research on hop plants: installing high trellis system, waiting at least three years before having plants ready for data collection, picking by hand each cone to determine yield performance *etc*. Moreover, in our country, hop market and beer industry have always been of secondary relevance as compared to grape and wine, so that hop cultivation has never been widespread in Italy and domestic demand for hop has been entirely satisfied by foreign countries. Nevertheless, beer production sensibly increased from 11.5 million hL (1997) to 13.5 million hL (2014) and its consumption raised from 14.5 to 17.7 million hL as well (Assobirra, 2009, 2014). Furthermore, the beer market still has a great potential as the rising number of microbreweries and brewpubs suggests (Assobirra, 2014). These new entities are increasingly interested in producing local beers using local raw materials, including hop.

This reveals a need for testing genotypes not only with original phytochemical traits but also characterised by good environmental adaptability and yield performance, to be introduced in cultivation or to be included in breeding programs, even more in that Countries or areas which are not typically hop producers.

The aim of this study is to identify, among a selection of 20 commercial cultivars, those suited to the Mediterranean climate with potential in terms of agronomic performance and brewing quality.

Materials and methods

Plant materials

Twenty female hop cultivars from USA, England, Germany, Czech Republic and New Zealand were used. These genotypes were selected among the hop cultivars most used to flavour beers in the Italian brewing industry.

Their maturity timelines and brewing use are reported in Table 1.

Location, experimental design and plant growth

The trial was carried out during three years, from 2013 to 2015, at the experimental farm of the University of Tuscia, Central Italy (42°26' N, 12° 04' E, altitude 310 m a.s.l.). Hop rhizomes were planted on April 13, 2011 in a silt clay soil. Hops were grown on a standard high trellis system where the wires were supported 8 m above the ground and plants spaced with 1.8 m between rows and 1.5 m in the row. The experimental design was a randomised complete block with three replicates for each cultivar (five plant plots). Weeds, pests and pathogens were chemically controlled to avoid any biological stress. Fertilisation was 80 kg $ha^{-1}year^{-1}$ P_2O_5 and 150 kg ha^{-1} $year^{-1}$ K_2O, while N was split in two rates of 50 and 50 kg ha^{-1} for spring (April) and late spring (May-June) treatments. Hop yard was irrigated when needed with a drip irrigation system. The total water amount was 200 mm in 2013, 55 mm in 2014 and 350 mm in 2015.

Meteorological data

Climate data records were obtained from the University's meteorological station located a few hundred meters away from the hop yard and are shown in Figure 1.

In 2013, during the growing period (March-September), the average T_{min} and T_{max} were 11.9 and 24.8°C, respectively. In 2014, average T_{min} and T_{max} were lower, with values of 11.6 and 23.8°C, respectively. Finally, 2015 average T_{min} and T_{max} reached the highest values of 12.7 and 25.7°C. Particularly, T_{max} in June and July 2013 reached values of

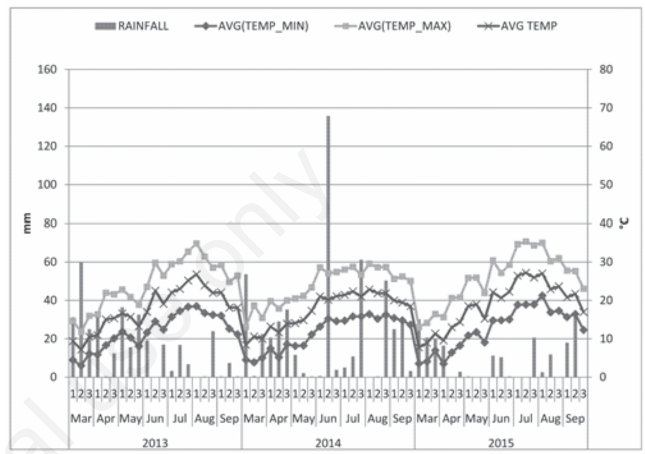

Figure 1. Decadal mean maximum, mean minimum and average air temperature and precipitation in Viterbo during 2013-2015 growing seasons.

Table 1. List of hops varieties used for the experiment, their maturity timelines, brewing use and origin.

Variety	Maturity timelines	Brewing use	Origin
Cascade	M	Dual purpose	US
Challenger	L	Dual purpose	UK
Columbus	M to L	Dual purpose	US
East Kent Golding	M	Aroma	UK
Fuggle	E to M	Aroma	UK
Hallertau Mittelfruh	E to M	Aroma	Germany
Hallertauer Aroma	E	Aroma	New Zealand
Hallertauer Bitter	E to M	Bittering	Germany
Hallertauer Magnum	L	Bittering	Germany
Hallertauer Taurus	L	Bittering	Germany
Hallertauer Tradition	E to M	Aroma	Germany
Hersbrucker Spat	L	Aroma	Germany
Northern Brewer	E to M	Dual purpose	UK
Omega	M	Bittering	UK
Perle	M to L	Dual purpose	Germany
Pheonix	E	Dual purpose	UK
Redsell's Eastwell	M to L	Dual purpose	UK
Tettnanger	E	Aroma	Germany
Whitbread Golding Variety	E to M	Dual purpose	UK
Yeoman	E	Bittering	UK

M, medium; L, late; E, early.

26.6 and 30.8°C, respectively, 27.7 and 27.8°C in 2014, 28.9 and 34.8°C in 2015. Similarly, rainfall amount in 2014 was higher than in 2013 and 2015, reaching in the period March-September about 500 mm *vs* 340 and 200 mm recorded during the 2013 and 2015 crop season, respectively.

Field measurements

Hops were grown under the same conditions and compared for phenology, productivity, growth and aromatic traits.

The phenological surveys were performed every week during the biological cycle using the *BBCH* centesimal scale (Meier, 2001), and growth stages (GS) of emergence of first shoots (GS 0: Sprouting 09), full flowering (GS 6: Flowering 65), beginning of cones formation (GS 7: Development of cones 71) and cones ripe for picking (GS 8: Maturity of cones 89) were recorded.

Temperature data and phenological records were used to estimate the hop thermal time following the formula:

$$\mathrm{GDD} = \Sigma_{days}\left(\frac{T_{max}+T_{min}}{2}\right) - T_{base} \quad (1)$$

where growing degree days (GDD) is thermal time (or heat sum) accumulated before a given stage is completed, °C-day (°Cd); T_{max} is the daily average maximum temperature; T_{min} is the daily average minimum temperature; T_{base} is the temperature below which the plant growth does not progress (McMaster and Wilhelm, 1997). According to Srečec *et al*. (2008), in the present study the T_{base} used for GDD calculation was 5°C. Degree days were summed beginning from 1st of January, since there were not cold periods of 5 or more consecutive days with a growing degree day value lower or equal to 0 and a 5-days average temperature less than or equal to –2°C (Johnson, 1991).

We used plant height as an indicator of plant vigour and adaptability. Hops height was measured at harvest time after plants were cut off.

At harvest, hop cones from each plot were collected and weighed. Considering the plants density, yield was reported as tons per hectare of dry matter cones. Dry weight was obtained in a oven with forced ventilation at 55°C until constant weight. Afterward, samples were vacuum-packed and stored at –20°C until they were used for brewing process.

Sensory evaluation

Thanks to a local brewery, in 2013 hops whole cones locally harvested and commercial ones were used to make beer through the dry hopping process using a standard first wort hop with cv Amarillo equal to every beer produced. As control was used beer obtained just from the standard first wort without the other aroma treatments. According to local production and commercial availability, it was possible to produce a total of 14 beers. In particular, the control was compared with beers dry-hopped with cones of the following cultivars: *Cascade*, *East Kent Golding* (EKG), *Fuggle*, *H. Tradition* and *H. Spat* using both local and commercial cones; *Columbus*, *Omega* and *Yeoman* using only local cones.

The sensory analysis was performed according to ISO 8589:2007, ISO 5492:2008, ISO 13299:2016 and the beer flavour wheel of the American Society of Brewing Chemists (ASBC) (ISO, 2007, 2008; ASBC, 2009; ISO, 2016).

After a preliminary screening session, the 14 coded beer samples analysed in this study were further evaluated using a descriptive sensory techniques in a purpose-built sensory laboratory.

The sensory panel consisted of 12 assessors, 3 women and 9 men (aged from 23 to 57), recruited from a pool of experienced in sensory analysis (staff and students) of the Food Technology Lab of the University of Tuscia.

For the sensory descriptive analysis method, the judges were trained using commercial beers to familiarise with the product, in order to recognise sensory differences and generate descriptive attributes.

Training of panellists included four sessions held over four weeks and involved attribute generation, discussion, consensus, scale use and agreement on reference standards. The panellists were asked to generate a vocabulary and compare samples for aroma, flavour, mouthfeel and aftertaste. A standardised system of beer aroma terminology was presented during the initial training sessions to assist with vocabulary development.

A total of ten attributes were selected by consensus to describe the beer samples, taking into account only flavour characters of major relevance for brewing. Six descriptors (sweet, bitter, salty, acid, astringent and pungent) belong to the taste family including the mouthfeel/palate sub-class, and four (floral, fruity, grassy and spicy) belong to odour class of flavour attributes.

The final step of training consisted in a scoring booth session whereby samples of beer were presented to the panel in individual booths, under controlled lighting and temperature, together with filtered water for palate cleansing.

Six formal evaluation sessions were undertaken and judges recorded the intensity of each attribute by scoring according to a 1-9 scale.

Each beer sample was poured immediately before the beginning of each session and served (30 mL at 22°C) in coded blue oil tasting glasses to avoid biases due to beer colour differences (International Olive Oil Council, 2007). Tasting glasses were covered with a lid (watch glass) and each beer was evaluated by each panellist in triplicate.

Statistical analysis

To investigate the effects of genetic and/or year factor and interactions between them on recorded variables, an analysis of variance (ANOVA) was performed using the statistical R software (R Development Core Team, 2006). When significant factors and/or interactions between them (F values) were observed, a pairwise analysis was carried out by the Fisher's least significant difference (LSD) test, both at the 0.95 and 0.99 confidence level. A simple correlation matrix was constructed for field measurements collected during the study and each pair of variables was correlated by calculating Pearson's correlation coefficients (r value).

Results

Crop phenology

Significant difference in plant phenology was detected among cultivars during the trial (Table 2). Averaged over years, *Cascade*, *Phoenix* and *Yeoman* were consistently registered as early cultivars in each phenological stage, while *Perle*, *EKG* and *H. Spat* as the late ones.

Sprouting (growth stage=09)

The difference between the earliest and latest cultivar for shoots emergence date was 159°Cd. *Columbus* and *Cascade* were the earliest varieties with a thermal time need of just 236.4 and 243.0°Cd respectively. Cultivars showing precocity in this stage were also *Whitbread Golding variety* (*WGV*) and *H. Magnum* with 251.9 and 258.3°Cd respectively. On the contrary, *Northern Brewer (NB)* and *EKG* ranked as late sprouting genotypes with 375.3 and 377.9°Cd, respectively, just before *Perle* which was the last cultivar to get shoots emergence with 395.4°Cd. *Omega*, *Fuggle* and *H. Taurus* performed as medium sprouting varieties showing a need of GDD accumulation of 315.3, 320.8 and 321.3°Cd, respectively.

Flowering (growth stage=65)

The difference between the earliest and latest cultivar for full flowering date was 364.6°Cd. *NB* was the first flowering cultivar with a need of just 653.8°Cd. Other cultivars showing earliness in this stage were *Tettnager*, *Yeoman* and *WGV* with 701.4, 742.0 and 752.0°Cd, respectively. On the contrary, *EKG* and *H. Spat* were the latest blooming genotypes with a thermal time needs (1013.1 and 1018.4°Cd, respectively) significantly higher than those necessary to other late flowering cultivars such as *Perle* and *Redsell's Eastwell* (986.4 and 993.7°Cd, respectively). *Omega* and *H. Mittlefruh* performed as medium flowering cultivars showing a cumulative thermal time of 868.1 and 867.9°Cd, respectively.

Development of cones (growth stage=71)

The difference between the earliest and latest cultivar for cone formation date was 560.8°Cd. *NB* was again the earliest cultivar with a thermal time accumulation of 878.0°Cd, significantly lower than those registered for other early cultivars such as *Yeoman* and *Phoenix* that accumulated 1002.1 and 1008.9°Cd, respectively. On the contrary, we ranked *Omega* as one of the latest cone-developing genotype (1418.9°Cd), just before *H. Mittlefruh* which accumulated 1438.8°Cd and was the last cultivar to get initial cone formation. *Columbus*, *Challenger* and *H. Magnum* performed as medium cultivars for this stage showing a thermal time need of 1184.2, 1185.3 and 1186.7°Cd, respectively.

Maturity of cones (growth stage=89)

The difference between the earliest and latest cultivar for harvest date was almost 500°Cd. The earliest cultivar for this stage was *Phoenix*, which needed 2021.8°Cd, a thermal time significantly lower than that necessary to the other early-maturing cultivar *Cascade* (2099.3°Cd). Other cultivars showing precocity for cones ripening were *H. Magnum*, *Yeoman* and *H. Tradition* with 2142.0, 2143.9 and 2145.8°Cd, respectively. On the contrary, *H. Aroma*, *Omega*, *Fuggle* and *H. Spat* performed as late-season genotypes and were harvested at 2451.0, 2467.6, 2485.3 and 2520.4°Cd, respectively. *NB* and *H. Bitter* accumulated 2301.3 and 2308.0°Cd to harvest, respectively and were both ranked as medium-ripening cultivars.

Yield

Significant variation in cone yield was found among tested cultivars (Table 3). *Cascade*, *H. Magnum* and *Yeoman* were the top performers during the whole study, reaching a 3-year average production of 2.12, 1.22 and 1.11 t ha^{-1}, respectively. In particular, it has to be noted that *Cascade* yielded significantly higher than *H. Magnum* and *Yeoman* in all growing seasons, even doubling their cone production level in 2014 and 2015. *H. Spat* ranked as fourth cultivar, yielding almost 0.9 t ha^{-1} (3-year mean). Averaged over three years, yields of the remaining cultivars were lower than 0.5 t ha^{-1}, with *Columbus*, *H. Aroma*, *NB*, *Perle* and *Pheonix* never reaching 0.3 t ha^{-1}. Averaged over tested varieties, yield was significantly higher in 2014 than those recorded in 2013 (+23.5%) and 2015 (+46.5%). Cultivars that showed yield significantly different across the years were those with medium to high 3-years

Table 2. Thermal time (°Cd) for sprouting, flowering, cones development and maturity, of the 20 cultivars under study.

Cultivars	Sprouting	Flowering	Development of cones	Maturity of cones
Cascade	243.0	820.4	1040.0	2099.3
Challenger	270.3	944.1	1185.3	2361.1
Columbus	236.4	978.1	1184.2	2375.2
East Kent Golding	377.9	1013.1	1345.0	2379.7
Fuggle	320.8	903.3	1323.5	2485.3
Hallertau Mittlefruh	296.4	867.9	1438.8	2366.7
Hallertauer Aroma	327.6	901.9	1112.0	2451.0
Hallertauer Bitter	366.1	772.5	1087.1	2308.0
Hallertauer Magnum	258.3	928.9	1186.7	2142.0
Hallertauer Taurus	321.3	981.3	1235.6	2231.4
Hallertauer Tradition	350.1	907.4	1089.9	2145.8
Hallertauer Spat	351.6	1018.4	1330.1	2520.4
Northern Brewer	375.3	653.8	878.0	2301.3
Omega	315.3	868.1	1418.9	2467.6
Perle	395.4	986.4	1250.6	2386.0
Pheonix	282.8	777.7	1008.9	2021.8
Redsell's Eastwell	327.7	993.7	1324.1	2390.2
Tettnager	351.5	701.4	1056.8	2337.6
Whitbread Golding Variety	251.9	752.0	1066.5	2367.4
Yeoman	286.4	742.0	1002.1	2143.9
LSD (P<0.05)	6.4	5.7	6.5	6.7
LSD (P<0.01)	8.5	7.5	8.6	8.8

LSD, least significant difference.

average production level (more than 0.4 t ha^{-1}). Conversely, no statistically significant results were detected over the years for the lowest yielding genotypes (9 out of 20).

The analysis of correlations among the studied parameters showed that yield was significantly influenced by heat accumulation to harvest (Table 4). In particular, the total increase of thermal time had a negative impact on the cone production (r=–0.5, P<0.05).

Plant growth

Significant variation in plant growth was observed among cultivars (Table 5). The high-yielding cultivars *Cascade*, *H. Magnum*, *H. Spat* and *Yeoman* were also the tallest ones in all three years, ranging between 4.6 and 6 m. Significant positive correlation (r=0.56, P<0.05) was found between cone yield and plant height (Table 4). Cultivars *Redsell's Eastwell* and *H. Taurus* performed similarly to the previous group but they were not equally productive. *Columbus*, *EKG* and *Perle* were the shortest cultivars, never reaching height of 4 m.

Sensory analysis

Results showed significant sensory differences among the beer samples in this study (Table 6). In general, the attributes of higher intensity recorded in the tested beers were: bitter, sapid, fruity, flowery, herby and spicy. Samples of beers produced with local cones were significantly bitterer as compared to commercials and control, with the exception of *H. Spat* hopped beer. Similarly, beers flavoured with local cones obtained scores markedly higher than commercial ones both in flowery and herby attributes, with the exception of *EKG,* which was not statistically different in herby taste. Moderate but not significant increase in spicy attribute was found for cv *H. Tradition*, *H. Spat* and *EKG vs* control, while local *Cascade* had significant higher score in the same taste. Moreover, local beers showed values significantly higher than commercial ones and control in sapid and pungent attributes when flavoured with *Cascade* and *Fuggle*, respectively. *Columbus*, *Yeoman* and *Omega*, have not had a corresponding commercial sample so they were compared to the other local cultivars. Specifically, *Columbus* showed a strong enhancement for the floral and fruity flavour, while *Yeoman* and *Omega*, increased the bitter taste and slightly the floral and grassy sensorial perception as compared to the control.

Discussion

Crop phenology

Plant development and thus phenological phases showed a significant difference among tested cultivars. This finding was due to the extreme heterogeneity in plant material as it consists of genotypes having different origins, background and maturity timelines. Generally, our results on hop precocity, or time to flowering, were consistent with information provided by hop nursery's varietal guide with the exception of *H. Aroma* and *EKG*, which we ranked as medium and late cultivars, respectively. Considering the hop growing period (from sprouting to maturity of cones), we found thermal time ranging between 1739°Cd of early-maturing cv *Pheonix* and 2168.8°Cd of late-maturing cv *H. Spat*. Similarly Srečec *et al.* (2008, 2013), recorded an average heat accumulation of 1800°Cd during a six-years study (2001-2006) in Croatia (latitude: 46 01' 51'' N) and 1766.2°Cd in Slovenia (latitude: 46 15' 13'' N) in 2012 for the medium-early cultivar *Aurora*.

Yield

In our study, cultivar *per* year interaction significantly affected hop production. Several authors highlighted the importance of yearly climatic pattern in determining an adequate growth, yield and quality for different hop cultivars (Bavec *et al.*, 2003; Srečec *et al.*, 2004, 2008; Pavlovic *et al.*, 2012, 2013).

Table 3. Cones yield (t ha^{-1}) of cultivars under study during 2013-2015 growing seasons.

Cultivar	2013	2014	2015	Mean
Cascade	1.98	2.62	1.78	2.12
Challenger	0.38	0.49	0.17	0.35
Columbus	0.30	0.21	0.26	0.26
East Kent Golding	0.26	0.27	0.22	0.25
Fuggle	0.30	0.47	0.27	0.34
Hallertau Mittlefruh	0.38	0.41	0.36	0.38
Hallertauer Aroma	0.19	0.12	0.16	0.15
Hallertauer Bitter	0.35	0.37	0.30	0.34
Hallertauer Magnum	1.25	1.45	0.97	1.22
Hallertauer Taurus	0.40	0.64	0.33	0.45
Hallertauer Tradition	0.46	0.60	0.32	0.46
Hallertauer Spat	0.81	1.04	0.75	0.87
Northern Brewer	0.17	0.14	0.15	0.15
Omega	0.43	0.41	0.40	0.41
Perle	0.19	0.13	0.16	0.16
Pheonix	0.19	0.26	0.18	0.21
Redsell's Eastwell	0.43	0.60	0.33	0.45
Tettnager	0.37	0.56	0.29	0.41
Whitbread Golding Variety	0.34	0.42	0.28	0.35
Yeoman	1.11	1.34	0.88	1.11
LSD (P<0.05)		0.12		0.07
LSD (P<0.01)		0.16		0.09

LSD, least significant difference for Cultivar × Year interaction and mean value.

Table 4. Pearson's correlation coefficients between cone yield, plant height and thermal time to flowering, cone development and maturity, averaged over three growing seasons.

	Cone yield	Height	Tt to flowering	Tt to cones development	Tt to cones maturity
Cone yield	1	0.557*	–0.284	–0.323	–0.500*
Height	-	1	–0.259	–0.129	–0.330
Tt to flowering	-	-	1	0.788**	0.303
Tt to cones development	-	-	-	1	0.491*
Tt to cones maturity	-	-	-	-	1

Tt, thermal time. *P<0.05; **P<0.01.

Cones production and its qualitative features were largely determined by weather factors such as air temperature and rainfall (Mozny *et al.*, 2009). In the present study, the highest yielding year was 2014 because of the favourable climatic conditions (without extreme heat events) registered from mid-June to late July: average temperatures between 20 and 22°C and more than 210 mm of total rainfall. In that period all cultivars were developing the reproductive stages of blooming and cone formation, which are fundamental phenological phases in determining final yield and production quality (Kucera and Krofta, 2009; Pokorný *et al.*, 2011; Potop, 2014). This is confirmed by our observation during cultivars reproductive growth occurred in the following driest year. In 2015, indeed, average temperatures varied between 20.7°C in mid-June to 27.2°C in mid-July with a total rainfall amount of just 41 mm. Moreover, maximum temperatures in July were even higher than 34°C with no precipitation from the third decade of June to the second decade of July. This protracted and intense drought probably caused higher percentage of floret abortion and cones formation on the lower insertion of hop plants (Srečec *et al.*, 2004), determining severe reduction in cone yield (Ceh *et al.*, 2012), especially for late maturing cultivars such as *Challenger* (–64.2%), *H. Magnum* (–33.3%), *H. Spat* (–28%) and *H. Taurus* (–48.6%). Furthermore, the significant decrease in cone yield which affected more than 50% of tested cultivars in 2015 confirmed results by Srečec *et al.* (2008), who found a negative correlation (r_s=–0.75, P<0.05), during the growth stage of cones formation, between average daily reference crop evapotranspiration in July and final cone yield.

Plant growth

Cultivar *per* year interaction significantly influenced final plants height. Hop growth dynamics were regular in 2013 and 2014 growing season thanks to the optimal weather conditions registered in April and May when the most intensive hop growth occurred. Conversely, rela-

Table 5. Plant annual and average height (m) reached by cultivars during 2013-2015 growing seasons.

Cultivars	2013	2014	2015	Mean
Cascade	6.00	6.00	5.23	5.74
Challenger	6.00	5.74	3.74	5.16
Columbus	3.64	2.83	2.00	2.82
East Kent Golding	4.00	3.94	1.97	3.30
Fuggle	5.93	4.57	3.22	4.57
Hallertau Mittlefruh	6.00	5.80	4.82	5.54
Hallertauer Aroma	6.00	5.80	4.38	5.39
Hallertauer Bitter	6.00	5.84	4.42	5.42
Hallertauer Magnum	6.00	5.80	4.61	5.47
Hallertauer Taurus	5.00	6.00	4.84	5.28
Hallertauer Tradition	6.00	5.70	4.16	5.29
Hallertauer Spat	6.00	6.00	4.88	5.63
Northern Brewer	4.44	4.15	3.50	4.03
Omega	5.80	5.70	3.65	5.05
Perle	3.64	3.61	3.31	3.52
Pheonix	6.00	5.70	4.23	5.31
Redsell's Eastwell	5.40	6.00	4.79	5.40
Tettnager	5.70	6.00	4.14	5.28
Whitbread Golding Variety	5.70	5.62	3.73	5.02
Yeoman	6.00	6.00	4.82	5.61
LSD (P<0.05)		0.58		0.33
LSD (P<0.01)		0.76		0.44

LSD, least significant difference for Cultivar × Year interaction and mean value.

Table 6. Mean scores obtained in sensory analysis by beers dry hopped with local and commercial cones and by control.

Attributes	Hop	Cascade	Columbus	East Kent Golding	Fuggle	Hallertauer Tradition	Hallertauer Spat	Omega	Yeoman	Control
Sweet	L	1.00^{b}	1.00^{b}	1.00^{b}	1.00^{b}	1.00^{b}	1.00^{b}	1.67^{ab}	1.33^{b}	1.00^{b}
	C	2.33^{a}	-	1.67^{ab}	1.67^{ab}	1.33^{b}	1.00^{b}	-	-	
Bitter	L	4.67^{bd}	4.00^{de}	5.33^{b}	6.67^{a}	4.00^{de}	5.00^{bc}	5.00^{bc}	4.33^{ce}	2.67^{f}
	C	2.33^{f}	-	3.67^{e}	2.67^{f}	2.33^{f}	6.67^{a}	-	-	
Sapid	L	4.33^{a}	4.67^{a}	2.00^{d}	3.67^{ac}	2.00^{d}	3.00^{bd}	3.67^{ac}	2.33^{d}	2.33^{d}
	C	3.00^{bd}	-	2.00^{d}	4.00^{ab}	2.33^{d}	2.67^{cd}	-	-	
Astringent	L	1.67^{ac}	1.00^{ac}	1.33^{ac}	2.00^{ab}	2.00^{ab}	1.00^{ac}	1.00^{ac}	0.67^{ac}	0.33^{bc}
	C	0.00^{c}	-	2.33^{a}	0.00^{c}	0.67^{ac}	0.33^{bc}	-	-	
Pungent	L	1.33^{bc}	0.67^{bc}	2.00^{b}	4.00^{a}	1.67^{bc}	1.67^{bc}	0.33^{bc}	2.00^{b}	1.67^{bc}
	C	0.33^{bc}	-	0.00^{c}	0.33^{bc}	0.33^{bc}	0.67^{bc}	-	-	
Acid	L	1.33^{ab}	0.00^{c}	2.00^{a}	0.67^{bc}	1.33^{ab}	1.33^{ab}	1.33^{ab}	0.00^{ce}	1.00^{ac}
	C	0.00^{c}	-	0.67^{bc}	0.00^{c}	0.00^{c}	2.00^{a}	-	-	
Floral	L	4.00^{b}	5.67^{a}	2.67^{ce}	3.67^{bc}	1.67^{ef}	3.67^{bc}	3.00^{bd}	4.00^{b}	1.33^{f}
	C	2.67^{ce}	-	1.33^{f}	2.33^{df}	0.00^{g}	1.33^{f}	-	-	
Fruity	L	3.33^{ad}	5.33^{a}	5.00^{ab}	2.33^{cd}	4.00^{ac}	2.33^{cd}	3.67^{ad}	3.00^{bd}	2.67^{cd}
	C	2.33^{cd}	-	2.00^{cd}	3.67^{ad}	1.67^{d}	2.00^{cd}	-	-	
Grassy	L	4.67^{ac}	4.33^{bd}	5.67^{a}	3.67^{ce}	2.67^{ef}	4.00^{cd}	3.33^{de}	3.67^{ce}	2.67^{ef}
	C	1.00^{g}	-	5.00^{ab}	1.67^{fg}	1.00^{g}	2.00^{fg}	-	-	
Spicy	L	4.67^{a}	1.00^{c}	3.67^{ab}	2.33^{bc}	3.67^{ab}	3.67^{ab}	2.00^{b}	4.00^{ab}	2.33^{bc}
	C	3.67^{ab}	-	4.00^{ab}	2.33^{bc}	3.67^{ab}	3.33^{ab}	-	-	

L, local; C, commercial. $^{a-g}$For each attribute means followed by the same letters are not statistically different (P<0.05).

tively high temperatures and poor rainfall in April and May 2015 (average temperature 15.0°C and only 20.0 mm of rainfall) caused an early start of the reproductive phase and, as a consequence, plants stopped growing. This finding is consistent with results by Srečec *et al.* (2004) who attributed low cone yield in 2003 to the irregular growth of plants connected with mild average temperatures (10.3°C) and low rainfall (22.4 mm) at the beginning of April.

Sensory analysis

Concerning the differences in flavour found in beers hopped with local and commercial cones, it is arguable that growing area affects sensory perception of beer. In particular, bitter, flowery and herby attributes, more than the others, seem to be influenced by hopping beer with local cones. Other studies demonstrated that cones of the same cultivars from different localities had different organoleptic profiles (Green, 1997; Kishimoto *et al*., 2008). In particular, Jelinek *et al.* (2012) pinpointed that drier and warmer growing areas produced hops with higher secondary metabolites content such as α- and β-bitter acids, essential oils, and polyphenols. These organic chemicals are commonly employed in brewing process and it is known that polyphenols are highly flavour-active compounds, with positive effects on mouthfeel (Goiris *et al*., 2014). This can explain why the beers dry-hopped with local cones generally had more intense flavour as compared to commercial ones and higher perception of astringency and bitterness (Mikyska *et al*., 2002; Aron and Shellhammer, 2010).

Conclusions

There was a big difference among cultivars for maturity timelines, plant height, cone yield, and beer quality. Hop growth and yield were significantly affected by yearly weather conditions. Particularly stress due to the shortage of rainfall and high temperatures, especially during flowering and cones formation, have had negative effect on plants growth and cones yield. Four cultivars (*Cascade*, *H. Magnum*, *H. Spat* and *Yeoman*) showed good yield performance under climatic condition of Central Italy and might be better explored in the future either to evaluate their drought and pest tolerance or the influence of different agronomic techniques on cones production and quality traits. With regard to beer quality, the results of the sensory analysis showed a more complex and appreciated profile for beers flavoured with local cones than those hopped with commercial products. These interesting results suggest the need to further investigate the effect of the growing area on hops quality and beer organoleptic properties. This study represents a first step to face challenges and opportunities for hop production in Central Italy and highlights the need for a screening of wild Italian genotypes to start hop breeding programs.

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