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BIOLOGY

Agronomic performance of *Humulus lupulus* L. varieties cultivated in organic and conventional systems in São Paulo center-west, Brazil

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ABSTRACT: Hop is a multifunctional specie; however, a large part of its production is destined for the beer market. In Brazil, all hop demand is imported, which has aroused interest in national production. Genetic material and cultivation systems can influence hops production. Thus, this study evaluated morphological and productive performance of hop varieties grown under organic and conventional management in the central-west region of São Paulo, Brazil. The hop yard was installed in the experimental area of the FCA/UNESP (São Paulo State University, School of Agriculture) – Botucatu, in November 2018, the data were collected in second year of production. A randomized block design was adopted, in 2 x 5 Split-Plot, being the main factor: cultivation systems (organic and conventional), and secondary factor: hop varieties (Columbus, Chinook, Nugget, Cascade, and Hallertau Mittelfrüeh), with four blocks and four plants per plot. Crop-specific morphological and productive parameters were evaluated. The results showed no significant influence of cultivation systems in morphological parameters. Regarding the varieties, Chinook, Cascade, and Nugget stand out for cone length. Columbus, Chinook and Cascade showed higher yields when grown in organic system, obtaining 1100.66, 1088.27 and 940.40 g of cones per plant, respectively. While, Hallertau Mittelfrüeh variety was the least productive in both systems, in organic system with 160.50 g per plant production, and 267.84 g per plant in conventional system, and, also showing lower cycle compared to the others.
Key words: Brazilian hops, tropical climate, genetic materials, organic and conventional cultivation, morphological and productive parameters.

Desempenho agronômico de variedades de *Humulus lupulus* L. cultivadas em sistema orgânico e convencional no centro-oeste paulista, Brasil

RESUMO: O lúpulo é uma espécie multifuncional, entretanto, grande parte de sua produção é destinada ao mercado cervejeiro. No Brasil, toda a demanda de lúpulo é importada, o que tem despertado interesse pela produção nacional. Fatores como o material genético e sistemas de produção podem influenciar na produção do lúpulo, sendo assim, o trabalho teve como objetivo avaliar o desempenho morfológico e produtivo de variedades de lúpulo cultivadas sob manejo orgânico e convencional na região centro–oeste paulista, Brasil. O campo de lúpulo foi instalado na área experimental da FCA/UNESP – Botucatu, em novembro de 2018 e os dados coletados no segundo ano de produção. Foi adotado o delineamento de blocos casualizados, em esquema de parcelas subdivididas 2 x 5, sendo o fator principal os dois sistemas de cultivo (orgânico e convencional) e fator secundário as cinco variedades selecionadas (Columbus, Chinook, Nugget, Cascade e Hallertau Mittelfrüeh), com quatro blocos e quatro plantas por parcela. Foram avaliados os parâmetros morfológicos e produtivos específicos da cultura. Os resultados demonstraram que os sistemas de cultivo não promovem alterações significativas nos parâmetros morfológicos. Quanto às variedades, destaca-se Chinook, Cascade e Nugget para comprimento de cone. Columbus, Chinook e Cascade apresentaram maiores produções quando cultivadas em sistema orgânico, obtendo 1100,66; 1088,27 e 940,40 g de cones por planta, respectivamente. Enquanto que, a variedade Hallertau Mittelfrüeh foi a menos produtiva em ambos os sistemas, no sistema orgânico com produção de 160,50 g por planta, enquanto que no convencional 267,84 g por planta, apresentando também menor ciclo quando comparada com as demais.
Palavras-chave: Lúpulo brasileiro, clima tropical, materiais genéticos, cultivo orgânico e convencional, parâmetros morfológicos e produtivos.

INTRODUCTION

The hop (*Humulus lupulus* L.) is a vine, angiosperm, dioica, perennial, herbaceous and annual flowering (BOCQUET et al., 2018). In inflorescences of this species are the lupulin glands, where is biosynthesis and storage of specialized metabolites such as terpenoids (DENBY et al., 2018), phenolic compounds, alpha and beta-acids, among others (BOCQUET et al., 2018), which confer to this horticultural plant its organoleptic and medicinal characteristics. In beer, these compounds act on microbiological and foam stability, as well on the flavors and aromas of beers (FERREIRA et al., 2018).

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Brazil is the largest importer of hop from South America. In 2020, 3,243 thousand tons of hop were imported, equivalent to US$ 57 millions (COMEXSTAT, 2020). The production of hop is recent in Brazil, with the first fields established in 2017, currently with an area of approximately 60 hectares. The beginning development of production chain should be accompanied by studies that evaluate management and development of genetic materials for the establishment of validated cultivation protocols for the different edaphoclimatic conditions of the country.

Hop varieties have been developed worldwide, their yields are influenced by genetic factors themselves, management conditions and environment of cultivation sites (LAFONTAINE et al., 2018). SOLARSKA & SOSNOWSKA (2015) reported significant increases in content of some chemical compounds of hops produced in organic system when compared to conventional system. This shows that organic management can increase synthesis of specialized metabolites of hops, which have commercial value for the beer and pharmaceutical markets.

Thus, this study evaluated the morphological and productive parameters of five varieties of hops grown in organic and conventional systems under the edaphoclimatic conditions of São Paulo center-west, Brazil.

MATERIALS AND METHODS

Experimental area

The experiment was conducted at the Department of Horticulture of the School of Agriculture (FCA) of UNESP (São Paulo State University) in Botucatu-SP, Brazil (latitude 22°50'S, longitude 48°26'W and altitude 791 m). According to Köppen, the climate is classified as subtropical with hot summer (*Cfa*). The hop yard was installed in November 2018, the research data were collected in second year of production (November 2019 to March 2020). In this period, the minimum average temperature was 17.94 °C, the maximum average was 28.45 °C and the rainfall was 1257.61 mm. The soil is clayey dystroferric Red Latosol (SANTOS et al., 2018).

The hop seedlings were purchased from a certified farm and were planted in pits, adopting a spacing of 3.2 x 1.0 m between plants. In right moment, four branches with 40 centimeters per plant were conducted in "V" in trellis. To conduction system, eucalyptus poles 7.5 m high and 12 to 14 cm in diameter were installed. Steel cables connected the posts forming a square, and wires were attached to the cables and stretched parallel to the planting lines.

For drip irrigation, two rows of drip tape were used per planting line, with an emitter spacing of 0.5 m and flow rate of 1.1 Lh $^{-1}$. Irrigation was managed automatically by ASI (MEDICI et al., 2010), a device that manages irrigation based on tensiometry, with the sensor installed below a seedling, at a depth of 0.20 m, in the root effective zone of the crop.

A complete chemical analysis of soil was performed in November 2019, after fertilization management and is described in table 1.

Treatments and Experimental Design

A randomized block experimental design was adopted in a 2 x 5 Split-Plot, being the main factor: two cultivation systems (conventional and organic), and, secondary factor: five varieties of hops ('Cascade', 'Colombo', 'Chinook', 'Hallertau Mittelfrüeh' and 'Nugget'), with four blocks and four useful plants per plot. The organic and conventional management systems were differentiated by fertilization and phytosanitary control, as shown below.

Conventional cultivation

Fertilizations were performed according to the needs observed in soil analyses. In first year, topdressing fertilizer was performed with calcium nitrate (375 kg.ha $^{-1}$) and urea (94 kg.ha $^{-1}$), potassium

Table 1 - Complete chemical soils analysis, layers 0-20 cm and 20-40 cm, of organic and conventional cultivation of *Humulus lupulus* L. varieties, Botucatu-SP, 2019.

Sample	pH	OM	P	K	Ca	Mg	CEC	V%	S	B	Cu	Fe	Mn	Zn
	CaCl2 g/dm^3	mg/m^3	---------- mmolc/dm ^{3}----------					%	----------mg/dm^3----------					
ORG 0-20	6.0	24	39	4.3	47	13	84	76	101	0.39	4.2	24	3.7	3.9
ORG 20-40	5.6	22	40	2.8	40	17	83	71	80	0.63	3.8	24	3.4	3.4
CONV 0-20	5.8	25	44	4.0	80	10	119	79	422	0.63	3.6	19	3.4	3.3
CONV 20-40	5.6	25	49	5.5	66	8	107	74	305	0.58	4.0	26	3.9	2.8

Source: Departamento de Solos e Recursos Ambientais da UNESP/FCA - Botucatu, SP.

chloride (186 kg.ha $^{-1}$) and micronutrients with MIB® (20 kg/ha). For phytosanitary control, applications were made with Abamectin (Abamex®) for mites (*Tetranychus urticae*), Fipronil (Regent®) for leaf-cutting ants. For powdery mildew (*Podosphaera macularis*), which was identified in first year of production, was applied Tecobunazole (Folicur®). In second year, the same sources were maintained and added chicken litter (3.12 t.ha $^{-1}$). Borate fertilization was performed with boric acid (4 kg.ha $^{-1}$), and leaf fertilization was performed with zinc sulfate (5 kg.ha $^{-1}$). The phytosanitary control of mites and ants was identical to the first year, and *Bacillus thuringiensis* (Dipel®) was applied control caterpillars.

Organic farming

Fertilizations were also performed according to the needs observed in soil analyses. In first year of cultivation, cattle manure, castor bean cake and potassium sulfate were used. For phytosanitary control, when the occurrence of pests and diseases was identified, sulfocalcic spray solutions were applied to mites (*Tetranychus urticae*), organic formicides (Bioisca®) for ants and powdery mildew (*P. macularis*) was sprayed with raw milk and Bordeaux mixture. In second year, fertilization was performed with Bokashi (1.5 t.ha $^{-1}$), castor bean cake (1.4 t.ha $^{-1}$), and organic poultry litter (2 t.ha $^{-1}$). Potassium sulfate (94 kg/ha), potassium silicate (312 kg.ha $^{-1}$), thermophosphate (203 kg.ha $^{-1}$), boric acid (4 kg.ha $^{-1}$) and bone meal (1 t.ha $^{-1}$) were used. Spraying was performed with SuperMagro biofertilizer, and biological activation of the soil was performed with EM (effective microorganisms). *Metharizium anisopliae* + *Beuaveria bassiana* (B Exchange ®) was applied to prevent pest control.

Evaluations

For harvest ideal point, cones samples were taken for determination of dry matter, adopting 20 to 23%, as established by MADDEN & DARBY (2012). After harvesting in field, the plants were taken to the Laboratory of Medicinal Plants of FCA/UNESP for further evaluations.

The morphological characteristics evaluated were as follows: formation height of first cones (m), measuring the distance from the soil surface to the first node from which fertile branches were emitted; length of internodes and lateral branches (cm), for both, six measurements were made above the first meter of the main branch; and cone length (cm), were selected 30 homogeneous cones of each plant and measured length.

The yield was determined by cones fresh weight (g) per plant. Technological maturity was calculated based on the number of days from the pruning of shoots in spring until the time when most cones reached technological maturity (SKOMRA et al., 2013).

Statistical analysis

The data obtained were subjected to analysis of variance (ANOVA), and the means were compared using Scott & Knott test at 5% probability using SISVAR software (FERREIRA, 2011).

RESULTS AND DISCUSSION

Morphological and productive characteristics of hop varieties grown in a tropical environment, reported under the same climatic and soil conditions, in two cultivation systems (organic and conventional) were elucidated for the first time in this study.

The results showed no significant differences between varieties and management for insertion height of cones (Table 2), with variations of 1.95 to 1.51 m between varieties 'Hallertau Mittelfrüeh' and 'Chinook', respectively, and 1.51 to 1.92 m between organic and conventional systems, respectively. The insertion height of first cones occurred similarly between treatments. This productive morphological parameter is directly related to production per plant, because, the internode length and the cone insertion height determine the number of productive lateral branches (MONGELLI et al., 2016).

There was no significant difference between varieties and management for the length of lateral branches, with corresponding means between approximately 37 and 65 cm (Table 2). The lateral branches develop from axillary buds in main stem; under field conditions, these branches can reach 50 to 200cm in length each, depending on the variety (HAUNOLD, 1983).

SKOMRA et al. (2013), recorded positive correlation between the length of the lateral branches and productivity. According to RYBACEK (1991), the yield of hops depends mainly of number and size of cones produced, which, in turn is affected by the number of productive lateral branches and their lengths (RYBACEK, 1991). RIGR et al. (1997), allege that the most productive hop genotypes, generally had lateral branches larger than 100 cm. In the present study, the largest length of lateral branches was obtained in varieties Chinook and Columbus in organic system, with 63 and 65 cm, respectively.

The hop undergoes different stages of phenological growth and reaches the peak of maturity

Table 2 - Variance analysis of productive characteristics of *Humulus lupulus* L. varieties grown under organic and conventional system: cones fresh weight (FW), insertion height of the first cones (HFC), internode length (IL), lateral branches (LB), days to maturation (DM) and cone length (CL), Botucatu-SP, 2020.

Variation sources	GL	----------Mean Squares----------					
		FW (g)	HFC (cm)	IL (cm)	LB (cm)	DM (days)	CL (cm)
Block	3	94135.33 ^{ns}	0.18 ^{ns}	11.34 ^{ns}	199.49 ^{ns}	13.96 ^{ns}	0.21 ^{ns}
Cultivation system	1	1969877.31 *	0.06 ^{ns}	177.87 ^{ns}	1063.88 ^{ns}	10.00 ^{ns}	4.13 ^{ns}
Residue (a)	3	100723.91	0.04	24.02	152.70	5.46	0.64
Varieties	4	374906.14 **	0.11 ^{ns}	6.2 ^{ns}	251.22 ^{ns}	1666.50 **	0.90 *
Cultivation system x Varieties	4	206836.94 *	0.11 ^{ns}	22.34 ^{ns}	357.00 ^{ns}	106.37 **	0.33 ^{ns}
Residue (b)	24	68855.31	0.09	10.94	207.09	8.32	0.25
Total	39	- -	- -	- -	- -	- -	
CV1(%)		53.14	11.72	23.55	23.42	1.58	23.56
CV2(%)		43.94	17.71	15.89	27.28	1.95	14.93

** and * = significant effect at the 1% and 5% probability levels by F test, respectively.
ns = non-significant effect at 5% probability level by F test.

around the 3rd to 5th year of growth, obtaining its maximum yield potential and specialized metabolite content at this age (MCADAM et al., 2014); therefore, in the 2nd year of cultivation, the crop has not yet been fully established. With the expected increase in production in coming years, the length of lateral branches also tends to increase, reaching the values reported in the literature for these varieties.

There was a significant difference in the average cone length for variety factor alone (Table 3). The varieties Cascade (3.68 cm), Chinook (3.61 cm) and Nugget (3.58 cm) had higher means than Hallertau Mittelfrüeh (2.87 cm) and Columbus (3.27 cm).

The cone length is associated with the point of physiological maturity of inflorescences (ČEH & ZMRZLAK, 2012). Studies conducted by KAVALIER et al. (2011), show there is a direct relationship between development of cones and the accumulation of specialized metabolites. However, it is important to note that cones of excessive size hinder the drying process, which may result in loss of quality (RAUT et al., 2020).

There was an interaction between varieties and cultivation systems for cones fresh weight (Table 4). The organic system promoted an increase in cones production in varieties Cascade (940 g), Chinook (1,088 g) and Columbus (1,110 g). Organic sources, commonly used in plant nutrition, have a greater complexity of chemical molecules, and eventually, nutrient release occurs gradually when compared to conventional fertilizers (VAN RAIJ, 2011). In hops, the nutrients most required for vegetative growth are nitrogen and potassium (GINGRICH et al., 1994). These nutrients may have their efficiency reduced due to losses in leaching processes and volatization of urea and potassium chloride used in conventional system in relation to organic compounds and silicate rocks used in organic system.

'Hallertau Mittelfrüeh' and 'Nugget' had no significant changes in their production due to the adopted systems. The varieties grown in the conventional production system did not differ from each other. 'Hallertau Mittelfrüeh' showed lower production in both systems adopted (Table 4). This result corroborated with literature (HOP VARIETIES, 2019) for 'Hallertau Mittelfrüeh', which is the least productive variety among all varieties analyzed. FAGHERAZZI (2020), when cultivating hops in conventional system in Lages - SC, also in second-year plants, found mean values of fresh cone production of 400 g per plant for 'Cascade' and 'Chinook' and 1,200 g per plant for 'Columbus'.

Table 3 - Mean cone length (CL) of *Humulus lupulus* L. varieties grown under organic and conventional system, Botucatu-SP, 2020.

Varieties	CL (cm)
Cascade	3.68 a
Nugget	3.58 a
Chinook	3.61 a
Hallertau Mittelfrüeh	2.87 b
Columbus	3.27 b

Means followed by same letters differ statistically in Scott & Knott test at 5% probability.

Table 4 - Mean cones fresh weight (FW) and technological maturity (TM) of *Humulus lupulus* L. varieties grown under organic and conventional system, Botucatu-SP, 2020.

Varieties	----------FW (g)----------		----------TM (days)----------	
	Organic	Conventional	Organic	Conventional
Cascade	940.40 aA	433.91 bA	157.00 aA	151.75 bA
Nugget	698.26 aA	587.95 aA	157.00 aA	152.75 bA
Chinook	1088.27aA	361.24 bA	152.50 aB	154.25 aA
Hallertau Mittelfrüeh	267.84 aB	160.50 aA	115.00 bC	128.00 aB
Columbus	1100.66 aA	332.66 bA	152.25 aB	152.00 aA

Means followed by same uppercase letters in same column and lowercase letters in same row do not differ statistically in Scott & Knott test at 5% probability.

There were significant differences between the cultivation systems and varieties for technological maturity, with more accelerated maturity in conventional system for the varieties Cascade and Nugget when compared to organic system, and for 'Hallertau Mittelfrüeh' in organic system. Cascade and Nugget were the varieties with the highest cycle, and the lowest cycle was recorded in the 'Hallertau Mittelfrüeh' (Table 4).

Hallertau Mittelfrüeh is the only early-cycle variety (KOHLMANN & KASTNER, 1975). 'Chinook', 'Columbus' and 'Nugget' are considered medium to late cycle, and 'Cascade' medium-cycle (KENNY & ZIMMERMANN, 1986), corroborating with the results obtained in this study.

The plant cycle is usually affected by growth conditions, such as management and growth region (FORSTER & SCHMIDT, 1994). FAGHERAZZI (2020), reported in 2nd year plants of the varieties Cascade, Chinook and Columbus cultivated in Lages - SC, technological maturity values of 180, 189 and 191 days, respectively. Can be observe that the cycle of these varieties was shorter in Botucatu than in Lages, probably due to the warmer climate in São Paulo interior, which may influence the more accelerated vegetative growth and early flowering of hops (ZMRZLAK & KAJFEŽ-BOGATAJ, 1996).

CONCLUSION

In the case of a temperate climate perennial crop, the hops in their second year of production have already indicated satisfactory morphological and productive performance in edaphoclimatic conditions in São Paulo center-west, Brazil.

The organic cultivation system showed production above the conventional system for the Collumbus, Chinook and Cascade varieties. Hallertau Mittelfrüeh was the least productive variety in both cultivation systems.

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DECLARATION OF CONFLICT OF INTEREST

We have no personal, academic, political or financial interests that may have influenced this study. Thus, the authors have no conflicts of interest to declare.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version. Bonfim, FPG supervised all work.

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