Ploidy and sex expression in monoecious hop plants

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Background and aims

In dioecious hop (*Humulus lupulus* L.) two sex chromosomes are responsible for the tentative XY mechanism (Shephard *et al*., 2000). Occasionally, spontaneously arisig hermaphrodite hop plants, carrying both flower types on the same plant, occur. They are often of predominantly male phenotype, but may be also predominantly female plants or plants with an approximately 50:50 ratio of male and female flowers (Neve, 1961; Shephard, 2000). Monoecious expression of sex in hop is most likely due to chromosomal number disorders of either triploid, tetraploid or aneuploid origin (Haunold, 1971; Shephard *et al*., 2000). In our study 58 monoecious hop plants, progenies of different crosses of diploid hop parents, were classified into six categories according to their level of expression of intersexuality and analyzed by flow cytometry to estimate ploidy level.

Methods

Young green leaves of 58 field-grown monoecious hop plants were used for flow cytometryc analysis. Estimations of relative DNA content by 4́,6-diamidino-2-phenylindole (DAPI) staining were performed as previously described (Šesek *et al*. 2000) using Partec PAS flow cytometer and *Trifolium repens* as an internal standard. Relative DNA content was also measured in diploid (cvs. Savinjski golding, Wye Target, Magnum, males '2/1', and '3/3'), triploid (cv. Celeia) and tetraploid (cv. Apolon) dioecious hop plants. During flowering monoecious plants were categorized into six classes according to their level of expression of female and/or male flowers (Figure 1) as described by Neve (1961).

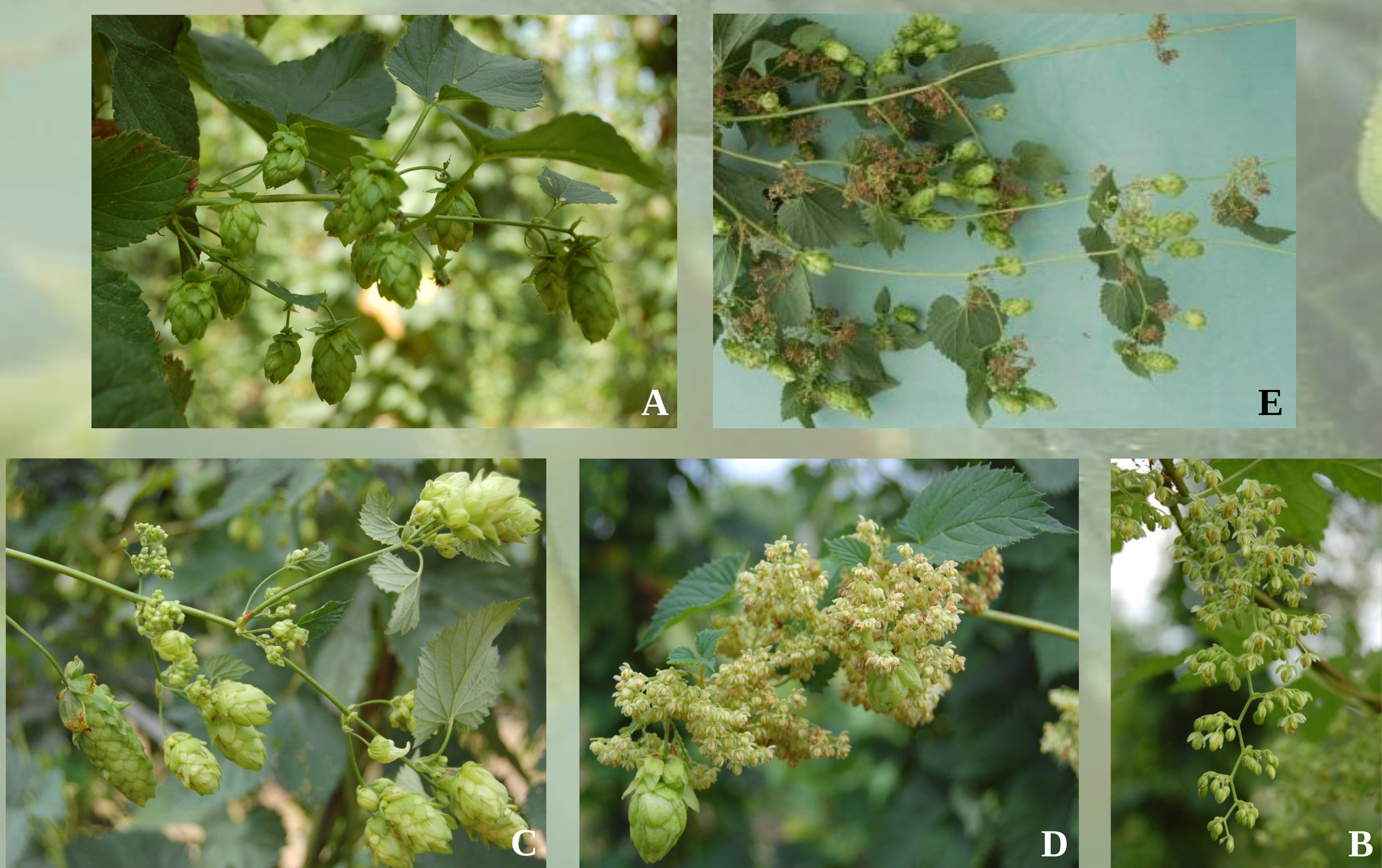

Fig. 1: A-Dioecious female hop cv. Savinjski golding; B-dioecious male hop '2/1'. Different levels of expression of female and male inflorescences in monoecious hops: C-predominantly female (Fm); D-predominantly male (Mf); E-approximately 50:50 ratio of female and male flowers (MF phenotype)

Results

In total 41% of monoecious plants were triploids, while the remainder were diploids. Since triploid monoecious plants originate from diploid parents, an effect of unreduced gametes from either male or female parent is suspected. The only one plant with just male inflorescences (MM phenotype) and all of the plants (10) with only female inflorescences (FF phenotype) were diploids. 22 morphologically predominantly female plants (Fm phenotype) were diploids, whereas all of the 24 predominantly male plants (Mf phenotype) were triploids and all of the triploids observed were of Mf phenotype. The only one plant with approximately equal share of male and female flowers (FM phenotype) was a diploid (Table 1, Figure 1). Not one almost entirely male plant with some hermaphrodite terminal flowers (Mh phenotype) was found.

Table 1: Sex expression and relative DNA content in monoecious hop plants.

Plant	Level of intersexuality	DNA content (pg)*	Plant	Level of intersexuality	DNA content (pg)*
1	Mf	6.54 ± 0.05	36	Fm	4.40 ± 0.01bcdefg
2	Mf	6.50 ± 0.03	39	Fm	4.46 ± 0.02defghi
3	Mf	6.54 ± 0.04	40	Mf	6.46 ± 0.04
4	MM	4.33 ± 0.04ab	41	Fm	4.41 ± 0.03bcdefgh
5	FF	4.40 ± 0.04bcdef	42	Mf	6.44 ± 0.06
6	Mf	6.60 ± 0.09	43	Mf	6.33 ± 0.06
7	FF	4.40 ± 0.03bcdefg	44	Mf	6.42 ± 0.02
8	Mf	6.50 ± 0.12	45	Fm	4.47 ± 0.03defghi
9	Mf	6.43 ± 0.09	46	Mf	6.47 ± 0.05
10	Mf	6.49 ± 0.09	47	Mf	6.40 ± 0.07
12	Mf	6.54 ± 0.02	49	Mf	6.37 ± 0.06
13	Mf	6.56 ± 0.07	50	Mf	6.49 ± 0.05
14	Mf	6.62 ± 0.05	51	Mf	6.35 ± 0.03
15	Fm	4.49 ± 0.05fghij	52	Mf	6.47 ± 0.02
16	Fm	4.57 ± 0.03j	53	Mf	6.48 ± 0.04
17	Mf	6.51 ± 0.08	54	Fm	4,35 ± 0,01bc
18	Mf	6.51 ± 0.02	55	FF	4.40 ± 0.02bcde
19	Fm	4.43 ± 0.04cdefghi	56	Fm	4.36 ± 0.03bc
20	Fm	4.51 ± 0.02ij	57	Fm	4.36 ± 0.02bc
21	Fm	4.45 ± 0.05defghi	59	Mf	6.39 ± 0.04
22	Fm	4.38 ± 0.05bcd	60	FM	4.41 ± 0.01bcdefghi
23	Fm	4.38 ± 0.01bcd	61	Fm	4.41 ± 0.01bcdefg
25	Fm	4.50 ± 0.03hij	62	FF	4.34 ± 0.02ab
26	FF	4.44 ± 0.02bcd	63	FF	4,36 ± 0,02bc
27	FF	4.40 ± 0.04bcdefg	64	Fm	4.46 ± 0.01defghi
28	FF	4.38 ± 0.02bcd	Dioecious hops		
29	Fm	4.42 ± 0.04bcdefghi	SG	FF	4.34 ± 0.02ab
30	FF	4.42 ± 0.03bcdefghi	WT	FF	4.38 ± 0.02bcd
31	Fm	4.42 ± 0.03bcdefghi	MAG	FF	4.37 ± 0.01bcd
32	Fm	4.41 ± 0.02bcdefg	2/1	MM	4.26 ± 0.03a
33	Fm	4.41 ± 0.02bcdefg	3/3	MM	4.26 ± 0.01a
34	Fm	4.49 ± 0.06efghij	CEL	FF	6.49 ± 0.02
35	FF	4.50 ± 0.01ghij	APO	FF	8.83 ± 0.03

SG- cv. Savinjski golding; WT- cv. Wye Target; MAG- cv. Magnum; 2/1- male 2/1; 3/3- male 3/3; CEL- cv. Celeia; APO- cv. Apolon
*Values followed by the same letter indicate no significant difference according to Bonferroni Test ($p<0.01$)

Conclusions

The predominantly male phenotype with a few female cones was observed to be connected with triploid chromosome number in monoecious hop plants. On the other hand predominantly female plants with some male flowers were diploids. Statistical comparisons at $p<0.01$ among means of DNA content in plants with diploid chromosome number indicated six plants, in which DNA content was significantly different and were presumed to be of aneuploid chromosome number (Table 1). Possible aneuploidy needs to be confirmed by cytological analysis of chromosome number.

Acknowledgements

This research was supported by the grant 2008-II/6056 from the Slovenian Research Agency

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