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Aroma Profiles of Dry-Hopped Ciders Produced with Citra, Galaxy, and Mosaic Hops

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Table S1. Semi-quantification of volatile compounds (mg/L) in juice, cider, and dry-hopped cider prepared from Gravenstein apples picked in Southwest Colorado. All analytes are listed in order of chromatographic retention time (shown in parentheses). Quantified values were determined using 3 internal standards: 4-methyl-2- pentanol (for alcohols), ethyl heptanoate (for esters, aldehydes, ketones, and volatile acids), and d6-myrcene (for terpenes).

Blue font indicates detection near/above perception threshold

Green font indicates unknown perception threshold

Red font indicates below perception threshold

	Ocimene (14.6 min)	Linalool (17.3 min)	Geraniol (24.6 min)	Cyclotene (25.6 min)	Carophyllene (31.7 min)	Humulene (33.1 min)	Famesene (33.3 min)
Juice (Day 0 pre-innoculation)	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 2	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 4	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 6	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 8	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 10	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 12	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 14	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 16	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 18	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 20	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 22	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 28	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 40	ND	ND	ND	ND	ND	ND	ND
Fermentation Day 47	ND	ND	ND	ND	ND	ND	ND
Finished Cider (Day 135)	ND	ND	ND	ND	ND	ND	ND

Dry Hopped Ciders (Days 139 and 142):							
Hop Day 5 Citra	<LOQ	0.007 ± 0.003	0.002 ± 0.001	ND	0.002 ± 0.001	0.004 ± 0.001	ND
Hop Day 5 Galaxy	<LOQ	ND	ND	ND	0.005 ± 0.002	<LOQ	<LOQ
Hop Day 5 Mosaic	<LOQ	0.003 ± 0.001	0.002 ± 0.001	ND	0.003 ± 0.001	0.010 ± 0.004	ND
Hop Day 8 Citra	<LOQ	ND	ND	ND	ND	0.005 ± 0.002	ND
Hop Day 8 Galaxy	ND	ND	ND	0.003 ± 0.001	<LOQ	<LOQ	ND
Odors and Perception Thresholds:							
He 2021 (Food Chem) Odor:							
Aparicio 1998 (J Agric Food Chem) Odor:							
Aparicio 1998 (J Agric Food Chem) Perception Threshold:							
Bingman 2020 (Beverages) Odor:							
Bingman 2020 (Beverages) Perception Threshold:							
Niu 2018 (Food Research Intl) Odor:							
Niu 2018 (Food Research Intl) Perception Threshold:							
Plotto 2004 (Flavour and Fragrance) Perception Threshold:							

Aros 2020 (Agronomy) Odor:	**warm herbaceous, green,terpenic**		**balsamic, hop, wood, spice**		
Eyres 2009 (Hop Essential Oil) Odor:				**balsamic**	
Schreiner 2020 (J Nat Prod) Perception Threshold:					
Schreiner 2020 (J Nat Prod) Odor:					
Miyazawa 2012 (J Essential Oil Research) Perception Threshold:	**0.034 mg/L**		**0.064 mg/L**	**0.160 mg/L**	**0.034 mg/L**
Escudero 2004 (J Ag Food Chem):					
Yu 2020 (Food Res Intl):					
Galvao 2011 (Food Re Intl):					
Moreno 2005 (Food Control):					

Table S2. Semi-quantified VOCs a (mg L-1) added to cider headspace as a result of dry hopping for 5 and 8 days with Citra, Galaxy, and Mosaic hops. Species in bold were quantified above the perception.

		Citra		**Galaxy**		**Mosaic**			
		Day 5	**Day 8**	**Day 5**	**Day 8**	**Day 5**	**Day 8**		
Terpenes	RT (min)	Concentration	Concentration	Concentration	Concentration	Concentration	Concentration	Odor Descriptor	PT (mg L-1)
β-myrcene	11.9	0.104 ± 0.041	0.278 ± 0.108	0.038 ± 0.015	0.044 ± 0.017	0.061 ± 0.024	0.070 ± 0.027	Citrus [b], Spicy [c]	0.036 [f]
D-limonene	13.5	0.002 ± 0.001	0.005 ± 0.002	-	-	<LOQ	<LOQ	Lemon, orange [c,d]	0.2 [f]
Linalool	17.3	0.007 ± 0.003	-	-	-	0.003 ± 0.001	0.008 ± 0.003	Citrus, floral [b,c]	0.001 [d]
Geraniol	24.6	0.002 ± 0.001	-	-	-	0.002 ± 0.001	0.003 ± 0.001	Floral [b], Rose [c]	0.01 [g]
Cyclotene	25.6	-	-	-	0.003 ± 0.001	-	0.002 ± 0.001	Curry, licorice [h]	-
β-Caryophyllene	31.7	0.002 ± 0.001	-	0.005 ± 0.002	<LOQ	0.003 ± 0.001	<LOQ	Woody [c], Balsamic [d]	0.069 [i]
Humulene	33.1	0.004 ± 0.001	0.005 ± 0.002	<LOQ	<LOQ	0.010 ± 0.004	0.004 ± 0.001	Woody [c], Balsamic [e]	0.16 [i]
Esters									
Ethyl propanoate	2.7	-	<LOQ	-	<LOQ	-	0.041 ± 0.061	Banana [j]	0.550 [k]
3-methylbutyl 2-methylpropanoate	13.1	0.033 ± 0.013	0.026 ± 0.10	0.188 ± 0.073	0.164 ± 0.064	0.023 ± 0.009	3.100 ± 1.209	Fruity, floral [l]	-
Methyl heptanoate	13.5	-	-	0.006 ± 0.002	-	-	-	Fruity [m]	0.004 [m]
Ethyl tridecanoate	25.58	-	-	-	0.005 ± 0.002	-	-	Fresh, floral [n]	-
Ethyl undecanoate	26.5	-	-	-	0.003 ± 0.001	-	-	Fresh, floral [n]	-
Ethyl nonanoate	26.5	-	0.002 ± 0.001	-	-	0.015 ± 0.003	-	Fruit [o]	3.151 [o]
Methyl geranate	27.7	-	0.059 ± 0.023	-	0.038 ± 0.015	-	6.310 ± 2.461	Sweet, candy [p]	-
Ketones									
Acetophenone	15.3	<LOQ	-	-	-	-	0.039 ± 0.015	Floral [q]	0.065 [q]
2-nonanone	16.8	0.003 ± 0.001	-	-	-	-	1.160 ± 0.452	Floral [q]	0.082 [q]
2-decanone	22.1	-	-	1.740 ± 0.679	1.240 ± 0.484	1.240 ± 0.484	1.160 ± 0.452	Citrus [r]	-
2-tridecanone	24.6	-	-	-	0.004 ± 0.002	-	0.187 ± 0.073	Herbal [r]	-
2-dodecanone	24.7	0.003 ± 0.001	0.015 ± 0.006	-	-	0.035 ± 0.010	0.495 ± 0.193	Fruity, orange [r]	-
2-undecanone	26.4	-	-	0.025 ± 0.010	0.018 ± 0.015	0.209 ± 0.082	4.720 ± 1.841	Fruity, citrus [r]	-
Higher Alcohols									
3-ethyl-4-methylpentanol	15.8	-	-	-	-	-	0.039 ± 0.015	Floral [s]	-
Volatile Acids									
Propanoic acid	10.9	**0.004 ± 0.002**	-	-	**0.008 ± 0.003**	-	-	**Spicy, soy [t]**	**0.003 [t]**

a This table is limited to analytes with published odor descriptors and/or perception thresholds. For a complete list of detected analytes, please refer to Supplementary Table S1. b(Wijaya et al., 2002), c(Miyazawa et al., 2012), d(Aros et al., 2020), e(Steinhaus, Wilhelm, & Schieberle, 2007), f(Plotto, Margaría, Goodner, Goodrich, & Baldwin, 2004), g(Cheong et al., 2011), h(Cullere, de Simon, Cadahia, Ferreira, Hernandez-Orte, & Cacho, 2013), i(Miyazawa et al., 2012), j(Niu, Yao, Xiao, Zhu, Zhu, & Chen, 2018), k(Yu et al., 2020), l(Fang & Qian, 2005), m(Pino et al., 2021), n(Shu, Zhang, Wang, Ren, & Wang, 2014), o(Xia, Liu, Wang, & Shuang, 2020), p(Wang & Kays, 2000), q(Yu, Xie, Xie, Chen, Ai, & Tian, 2021), r(Van Opstaele et al., 2012), s(Shimoda, Nishihara, Ozawa, Takabayashi, & Arimura, 2012), t(Tian, Xu, Chen, & Yu, 2019).