Effects of Barley Variety and Growing Locations on Beer Sensory Attributes

Yueshu Li, Andrew Nguyen, Bryce Lodge, Aaron Onio, Sherwin Santiano, Peter Watts

2022 Brewing Summit, Providence, Rhode Island, USA

MASTER BREWERS ASSOCIATION OF THE AMERICAS EST 1887

UNITED WE BREW

Introduction

- Beer's sensory characteristics are one of the critical quality attributes for beer drinker's acceptance and satisfaction.
- To date, the "flavour origins of beer" are not well defined.
- Our understanding of how barley/malt directly contributes to beer flavours is limited, though we may agree with the statement, "malt is the soul of beer".
- Realizing barley's impact on a beer's sensory attribute is very important for the malting and brewing industry in order to accept new varieties and harness their quality potential
- This study examined the effects of barley variety (G), growing location (E), and their interactions (G x E) on flavour attributes of the all-malt beers brewed with AAC Connect, CDC Bow, CDC Copeland and Harrington barley malts.
- Some of the underlying organic compounds (volatile and non-volatile) in wort and beer, which may be associated with beer sensory attributes, were assessed.
- Additionally, the associations between beer sensory attributes and the quality parameters of barley, malt, and beer, were assessed.

Barley Material

- **AAC Connect**, **CDC Bow**, **CDC Copeland** and **Harrington** barley were grown at 3 locations: Brandon, MB, Lacombe, AB, and Saskatoon, SK, Canada in 2018 & 2019 crop years
- **Lacombe** is located at black grey soil zone with 533 mm precipitation/yr.
- **Saskatoon** is located at brown soil zone with 465 mm precipitation/yr.
- **Brandon** is located at black soil zone with 610mm precipitation/yr.

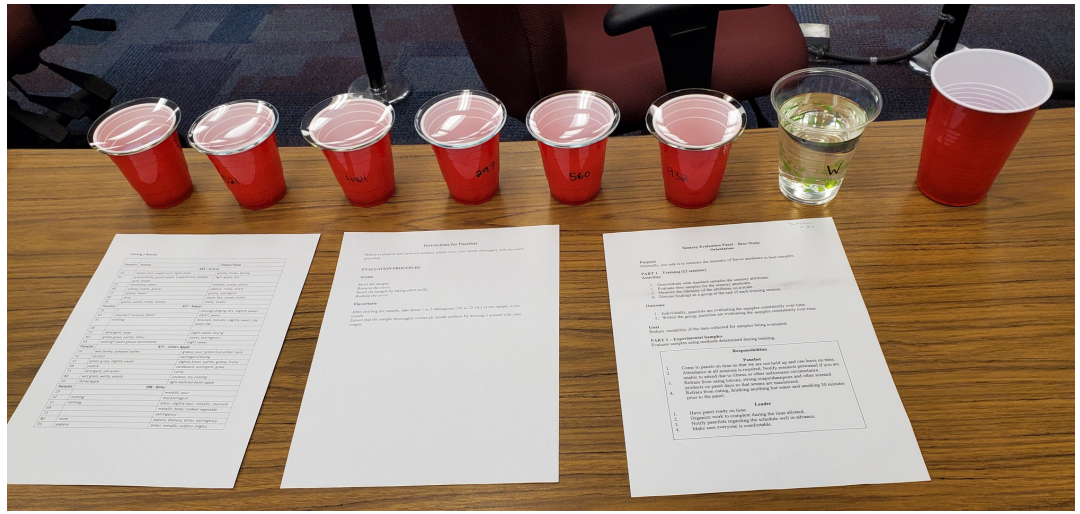
Barley plots prior to harvest at Brandon, AB

Malting and Brewing

- Malting trials (by variety, location and crop year) were conducted at CMBTC using a 5kg-pilot malting system, all under identical processing conditions
- All malt beers were brewed for each malt sample using a nano-brewing system at CMBTC using identical brewing procedures.
- Magnum hops (Hops Direct, BC) were used for hopping
- Fermentation was carried out at 19°C for 7 days using American Ale yeast (Wyeast, OR) with a pitch rate of 1.25 x 10^6 cells/ml/°P

Sensory Evaluation

- Descriptive sensory analysis of the beer samples was performed by trained panelists at the CMBTC
- Panelists were trained to detect the sensory components selected for this study at varying concentrations
- Beers were poured from 20L kegs into pitchers and placed in an ice bath until ready to be poured into sample cups. The beer samples were evaluated at approximately 12°C.



Physical and Chemical Analysis

Non-Volatile Compounds

Water-soluble extraction and untargeted analysis by:

- Liquid Chromatography-Quadrupole Time of Flight Mass Spectrometry (LC-QTOF-MS (Agilent 1260/ 6538)). Library with 250,000 compounds.
- Nuclear Magnetic Resonance (NMR (AVANCE III 600 MHz). Library with 1400 compounds.

Volatile Organic Compounds (VOCs) Analysis

- Extraction using a Likens Nickerson Solvent Extraction
- Gas Chromatography-Mass Spectrometry (GC-MS)

Effects of G, E & G x E interaction on Malt

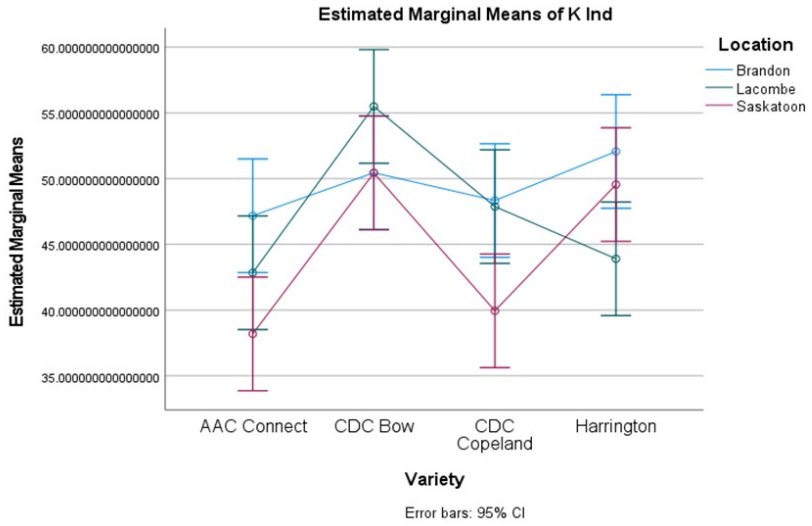
All **13** malt quality parameters tested showed significant effects of G & E;

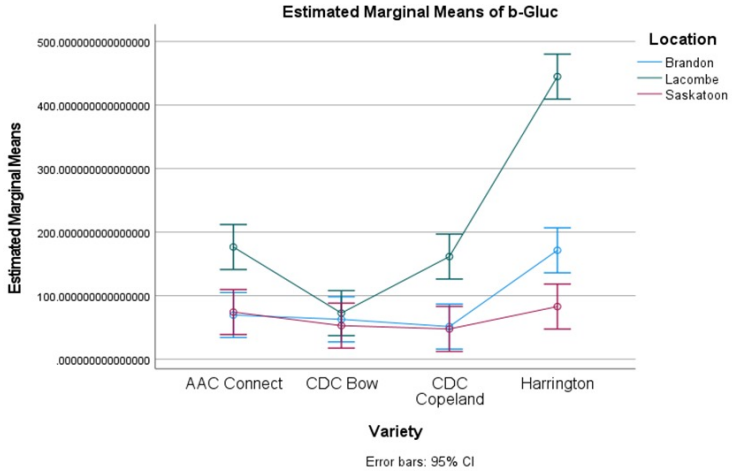
9 out of the **13** parameters showed significant G x E interaction; friability, extract, total protein, and alpha amylase showed no significant G x E interaction;

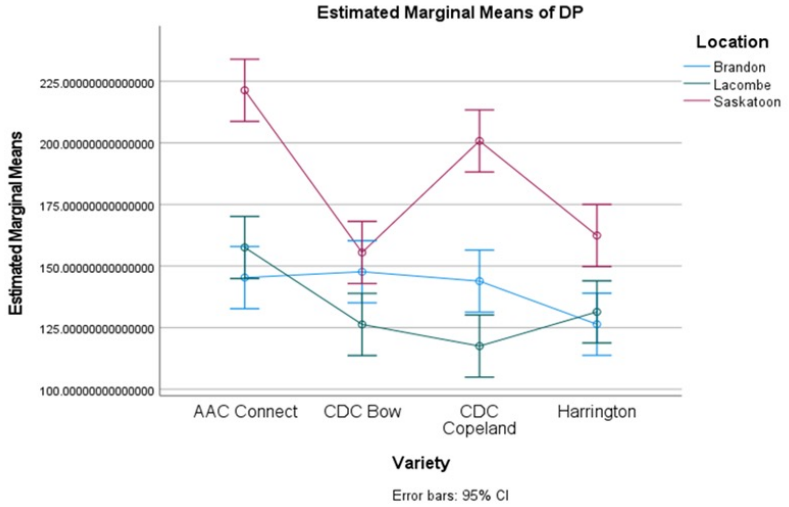
In addition, crop year variations were recorded.

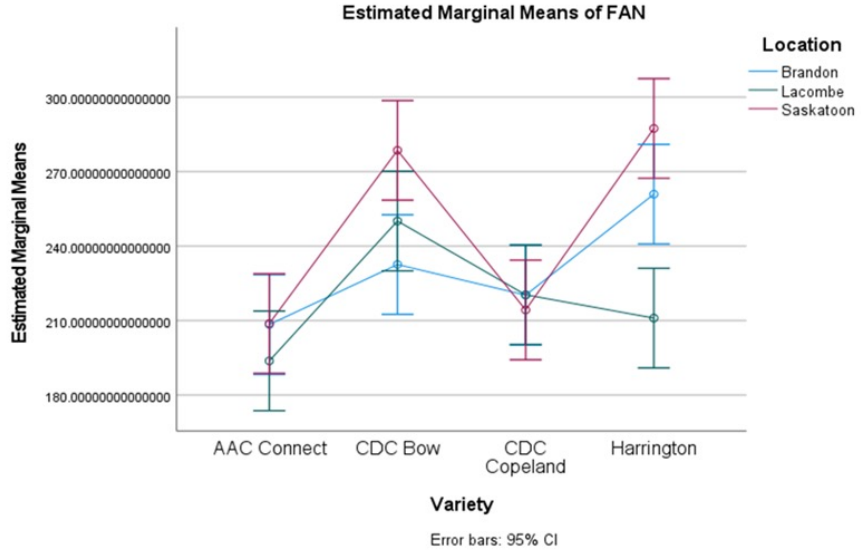
	Crop year	Source of Variation F-values and Probability		
Measurement		Variety	Location	Variety x Location
Friability	2018	4.12 **	9.20 ***	1.41 NS
	2019	14.8***	43.3 ***	†
F-extract	2018	15.08 ***	23.40 ***	2.11 NS
	2019	2.0 NS	7.2 **	†
F/C	2018	60.02 ***	12.69 ***	1.24 NS
	2019	52.9. ***	57.6 ***	20.7 ***
Soluble protein	2018	12.32 ***	9.45 ***	2.47 *
	2019	7.9 **	9.1 **	†
Total protein	2018	3.12*	34.57 ***	1.69 NS
	2019	1.2 NS	41.7 ***	†
KI	2018	10.35 ***	31.43 ***	2.97 *
	2019	12.5 ***	6.4 *	3.7 *
β-glucan	2018	2.09 NS	0.58 NS	0.22 NS
	2019	65.5 ***	97.4 ***	22.5 ***
Viscosity	2018	1.66 NS	0.02 NS	0.055 NS
	2019	34.3 ***	22.4 ***	18.8 ***
DP	2018	3.27 *	1.84 NS	0.81 NS
	2019	22.1 ***	93.6 ***	9.5 ***
α-amylase	2018	3.02 *	0.85 NS	0.41 NS
	2019	0.6 NS	4.2*	†
Color	2018	2.93 *	11.70 ***	1.29 NS
	2019	52.2 ***	28.7 ***	16.8 ***
pH	2018	19.53 ***	45.46 ***	3.01 ***
	2019	10.2 **	1.3 NS	3.3 *
FAN	2018	26.26 ***	3.82 *	0.89 NS
	2019	22.5 ***	9.7 **	5.2 **

Effects of G, E & G x E Interaction on Malt







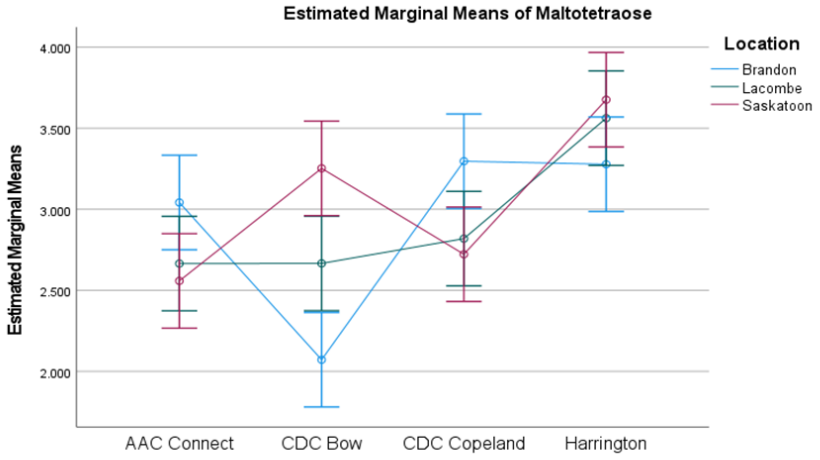


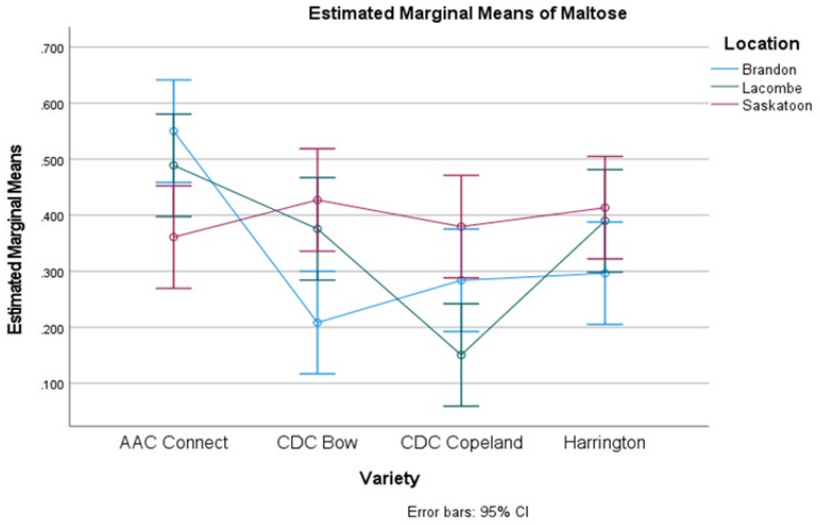
Effects of G, E & G x E Interaction on Beer

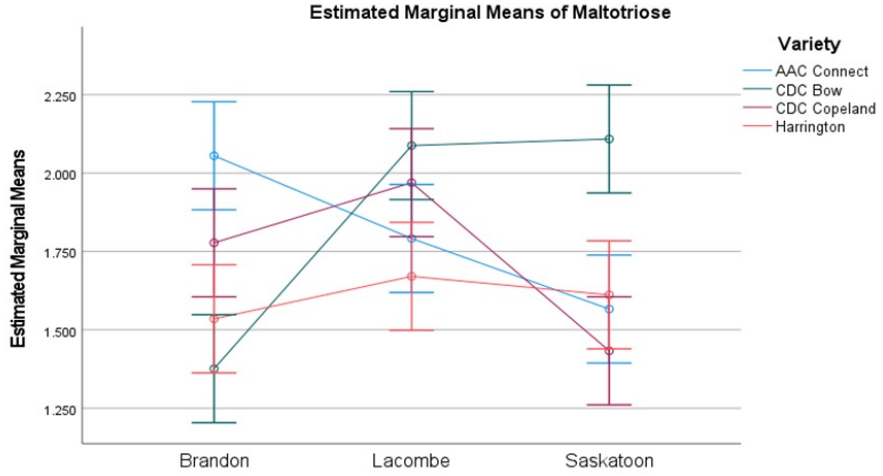
		Source of Variation F-values and Probability			Variety (Mean, n=6)				Location (Mean, n=8)		
Measurement		Variety	Location	Variety x Location	CDC Bow	AAC Connect	CDC Copeland	Harrington	Brandon	Lacombe	Saskatoon
Specific gravity	2018	170.16 ***	171.69 ***	42.84 ***	1.0035^{d}	1.0047^{b}	1.0043^{c}	1.0052^{a}	1.0047^{a}	1.0037^{b}	1.0048^{a}
	2019	7.7 **	8.4 **	†	1.0043^{ab}	1.0041^{ab}	1.0032^{b}	1.0051^{a}	1.0034^{b}	1.0046^{a}	1.0046^{a}
AE (°P)	2018	168.52 ***	178.61 ***	43.62 ***	0.90^{d}	1.21^{b}	1.10^{c}	1.34^{a}	1.22^{a}	0.95^{b}	1.24^{a}
	2019	8.0 **	8.7 **	†	1.11^{a}	1.06^{ab}	0.83^{b}	1.31^{a}	0.87^{b}	1.18^{a}	1.18^{a}
ABV (%)	2018	63.55 ***	39.07 ***	7.54 ***	5.10^{b}	5.19^{a}	4.94^{c}	4.86^{d}	5.04^{b}	5.11^{a}	4.91^{c}
	2019	13.5 ***	10.5 ***	†	5.07^{b}	5.10^{ab}	5.23^{a}	4.91^{c}	5.19^{a}	5.04^{b}	5.00^{b}
ADF (%)	2018	147.91 ***	162.19 ***	36.31 ***	91.51^{a}	89.11^{b}	89.56^{b}	87.35^{c}	88.72^{b}	91.15^{a}	88.27^{c}
	2019	8.4 **	8.8 **	†	89.71^{ab}	90.16^{ab}	92.33^{a}	87.68^{b}	91.92^{a}	88.99^{b}	89.00^{a}
RDF (%)	2018	148.20 ***	161.01 ***	36.01 ***	75.00^{a}	73.16^{b}	73.43^{b}	71.70^{c}	72.82^{b}	74.71^{a}	72.43^{c}
	2019	8.4 **	8.8 **	†	73.60^{ab}	73.95^{ab}	75.67^{a}	71.98^{b}	75.35^{a}	73.03^{b}	73.03^{b}
COE (°P)	2018	66.82 ***	14.91 ***	8.78 ***	10.61^{b}	11.05^{a}	10.50^{b}	10.59^{b}	10.79^{a}	10.68^{b}	10.59^{b}
	2019	30.3 ***	14.7 ***	8.0 **	10.75^{a}	10.76^{a}	10.78^{a}	10.64^{b}	10.75^{a}	10.76^{a}	10.69^{b}
RE (°P)	2018	166.83 ***	146.56 ***	43.41***	2.77^{c}	3.10^{a}	2.91^{b}	3.12^{a}	3.06^{a}	2.82^{b}	3.04^{a}
	2019	6.6 **	8.3 **	†	2.96^{ab}	2.92^{ab}	2.74^{b}	3.11^{a}	2.76^{b}	3.02^{a}	3.01^{a}
Color (SRM)	2018	9.98 ***	21.24 ***	†	2.51^{a}	2.13^{b}	2.11^{b}	2.45^{a}	2.60^{a}	2.22^{b}	2.09^{b}
	2019	87.5 ***	38.0 ***	21.5 ***	3.39^{a}	2.20^{b}	2.14^{b}	3.25^{a}	2.58^{b}	2.47^{b}	3.18^{a}
pH	2018	26.03 ***	31.38 ***	5.36 ***	4.39^{a}	4.44^{a}	4.43^{a}	4.30^{b}	4.42^{a}	4.42^{a}	4.32^{b}
	2019	0.1 NS	1.2 NS	†	4.46^{a}	4.47^{a}	4.46^{a}	4.46^{a}	4.46^{a}	4.44^{a}	4.49^{a}
IBU	2018	79.64 ***	25.42 ***	9.53 ***	13.34^{a}	9.74^{b}	14.03^{a}	13.22^{a}	13.67^{a}	12.05^{b}	12.03^{b}
	2019	3.4 *	0.3 NS	†	15.21^{ab}	13.16^{b}	14.69^{ab}	15.50^{a}	14.58^{a}	14.40^{a}	14.93^{a}

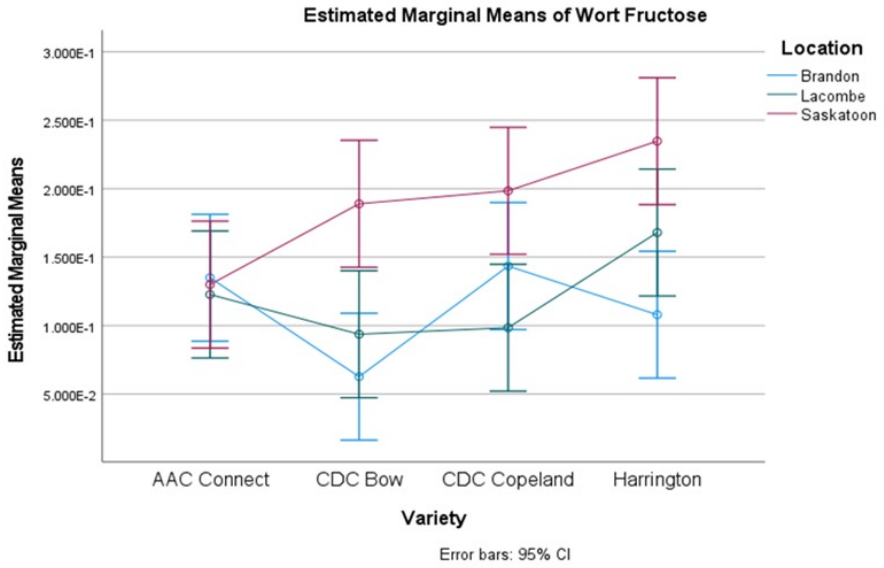
- All **9 beer quality parameters** tested showed significant effects of **G & E** although there were crop year variations
- For **2018 crop beer**, all 9 quality parameters showed significant G & E interaction except for beer color; in contrast, for **2019 crop beer** only COE and PH showed significant G x E interaction

Effects of G, E & G x E Interaction on Beer (sugars)









Attributes Definitions (Aroma and Flavor)

Attribute	Definition
Ethyl Acetate	Aroma/Flavor, what was described as nail polish
Acetaldehyde	Aroma/Flavor, what was described as green apple
Isoamyl Acetate	Aroma/Flavor, what was described as banana-like
Dimethyl sulphide	Aroma/flavor, what was described as cooked/creamed corn
Grainy	Aroma/flavor associated with malt kilned at a relatively low temperature
Malty	Aroma/flavor associated with malt kilned at an increased temperature
Sweet	Taste associated with sucrose in solution
Bitter	Taste associated with iso-alpha-acids in solution
Astringent	Feeling in the mouth associated with drying like that produced by saponins in solution

In total nine beer flavor attributes were assessed by CMBTC inhouse panelists

Effects of G, E & G x E Interaction on Sensory Attributes

8 of the 9 sensory attributes tasted showed no significant G and E effects, except for Acetaldehyde.

CDC Copeland beer had acetaldehyde levels significantly higher than Harrington beer.

This suggests all four varieties evaluated in this study were relatively close to each other as far as the sensory properties are concerned.

Panelist	Source of Variation - F-values and Probability			Variety (n=126)			
Sensory Attribute[1]	Variety(G)	Location(E)	G x E	AAC Connect	CDC Bow	CDC Copeland	Harrington
2018 crop							
Dimethyl Sulfide	0.4 NS	0.2 NS	†	2.5 (1.6)	2.3 (1.6)	2.5 (1.6)	2.5 (1.7)
Grainy	0.3 NS	0.1 NS	†	2.3 (1.2)	2.4 (1.2)	2.4 (1.4)	2.3 (1.2)
Malty	0.3 NS	1.6 NS	†	2.0 (1.4)	2.1 (1.2)	2.2 (1.4)	2.0 (1.3)
Sweet	1.0 NS	0.3 NS	†	1.5 (1.1)	1.6 (1.3)	1.8 (1.2)	1.6 (1.2)
Bitter	0.9 NS	0.5 NS	†	2.6 (1.2)	2.5 (1.3)	2.7 (1.5)	2.4 (1.3)
Astringent	1.5 NS	0.4 NS	†	2.6 (1.8)	2.4 (1.5)	2.7 (1.7)	2.3 (1.5)
2019 crop							
Ethyl Acetate	1.1 NS	0.0 NS	†	1.0 (1.2)	1.2 (1.1)	1.0 (1.1)	0.9 (1.0)
Acetaldehyde	4.0 **	0.2 NS	†	1.1^{ab}(1.1)	1.2^{ab}(1.2)	1.4^{a} (1.2)	1.0^{b} (1.0)
Isoamyl Acetate	0.1 NS	2.9 NS	†	0.6 (0.7)	0.6 (0.8)	0.6 (0.8)	0.6 (0.9)
Dimethyl Sulfide	0.6 NS	2.1 NS	†	1.2 (1.4)	1.2 (1.1)	1.3 (1.3)	1.1 (1.3)
Grainy	1.3 NS	2.2 NS	†	1.4 (1.4)	1.5 (1.3)	1.2 (1.1)	1.2 (1.1)
Malty	0.6 NS	0.3 NS	†	1.3 (0.9)	1.2 (1.0)	1.3 (1.1)	1.2 (1.0)
Sweet	1.1 NS	0.0 NS	†	1.2 (1.0)	1.2 (0.8)	1.3 (0.9)	1.3 (0.9)
Bitter	2.6 NS	0.1 NS	†	2.3 (1.1)	2.0 (1.1)	2.0 (1.1)	2.1 (1.0)
Astringent	1.0 NS	0.9 NS	†	1.6 (1.1)	1.8 (1.2)	1.8 (1.2)	1.6 (1.1)

Evaluated using a 9-point scale.

Effects of G, E & G x E Interaction on Sensory Attributes

GC-MS				Mean Values						
	Source of Variation - F-values and Probability			Variety (n=12)				Location (n=16)		
Measurement	Variety (G)	Location (E)	G x E	CDC Bow	AAC Connect	CDC Copeland	Harrington	Brandon	Lacombe	Saskatoon
Acetal Aldehyde (mg/L)	2.33 (0.1255)	0.06 (0.9408)	0.71 (0.6456)	2.048 [a] (0.476)	2.341 [a] (0.441)	2.512 [a] (0.308)	1.909 [a] (0.342)	2.240 [a] (0.496)	2.164 [a] (0.356)	2.203 [a] (0.518)
DMS (mg/L)	1.43 (0.2823)	0.57 (0.5806)	1.22 (0.363)	0.054 [a] (0.055)	0.032 [a] (0.039)	0.012 [a] (0.019)	0.027 [a] (0.013)	0.022 [a] (0.014)	0.031 [a] (0.035)	0.041 [a] (0.053)
Isobutyl Aldehyde* (mg/L)	51.1*** (<.0001)	4.00* (0.0467)	1.12 (0.407)	0.168 [b] (0.001)	0.174 [a] (0.002)	0.166 [c] (0.001)	0.167 [bc] (0.001)	0.170 [a] (0.004)	0.169 [ab] (0.003)	0.168 [b] (0.002)
Ethyl Acetate (mg/L)	1.57 (0.2472)	0.44 (0.6568)	0.37 (0.884)	3.325 [a] (0.352)	3.14 [a] (0.726)	2.451 [a] (1.027)	3.213 [a] (0.298)	3.23 [a] (0.662)	2.988 [a] (0.881)	2.879 [a] (0.628)
Isopentyl Acetate* (mg/L)	1.71 (0.2181)	0.08 (0.9225)	0.44 (0.8364)	0.085 [a] (0.064)	0.765 [a] (1.61)	1.836 [a] (2.1)	0.111 [a] (0.048)	0.533 [a] (1.215)	0.839 [a] (1.527)	0.727 [a] (1.696)

*Described as apple/banana/fruity

GC-MS data indicated significant effects of G and E were for **isobutyl aldehyde**; **AAC Connect beer** with the highest concentration of Isobutyl Aldehyde and **CDC Copeland beer had the lowest**. Locationally, **Brandon beer** had the highest isobutyl aldehyde and **Saskatoon beer** had the lowest.

Effect of variety on Volatile compounds detected in the beers of 2019 crop

Out of the **64** volatile compounds detected in 2019 crop beers, **43** showed significant varietal differences

Chemical Class	Volatile	Odour	Source of Variation - F-values and Probability	Variety Mean Values (ug/L, ppb)			
				CDC Bow (n=3)	AAC Connect (n=4)	CDC Copeland (n=3)	Harrington (n=3)
Amine	3-Isoquinolinamine ; 3-Aminoisoquinoline		16.60 ***	0.29^{a} (0.15)	ND	ND	0.33 (0.08)
Alkane	Pentane, 2-chloro		14.62 ***	3.26^{bc} (0.94)	6.68^{a} (2.07)	3.86^{b} (0.11)	1.36^{c} (1.00)
Alkene	1-Octene, 3-methyl-		9.35 **	425.65^{b} (173.16)	762.86^{a} (240.19)	415.71^{b} (99.05)	0.36 (0.29)
Ester	Acetic acid butyl ester	Sweet, ripe banana, tutti frutti, tropical and candy-like with green nuances, Solvent, fruity, pear, pineapple, berry	45.06 ***	0.82^{b} (0.06)	0.47^{d} (0.06)	1.01^{a} (0.03)	24.98 (31.48)
Ester	Hexanoic acid, 1-methylethyl ester	fruity pineapple loganberry berry	25.05 ***	4.58^{a} (0.44)	2.70^{c} (0.13)	3.33^{bc}(0.04)	0.16^{ab} (0.12)
Ester	Octanoic acid, ethyl ester	Fruity, Floral, Banana, Pineapple, Brandy	10.53 ***	0.10^{a} (0.01)	0.07^{b} (0.01)	0.06^{b} (0.01)	0.09^{a} (0.02)
Ester	Propanoic acid, 1-methylethyl ester	banana Sweet fruity rum juicy fruit grape pineapple	7.03 **	4.29^{a} (1.00)	2.40^{bc} (0.52)	3.98^{ab} (0.34)	2.15^{c} (1.30)
Ester	Isobutyl acetate	Apple, banana fruity aroma in sweet wines	5.74 **	1.34^{a} (0.21)	1.19^{ab} (0.21)	1.52^{a} (0.20)	1.31 (0.29)
Ester	Acetic acid pentyl ester ; Amyl acetate	Banana, apple	62.54 ***	24.93^{a} (2.08)	11.67^{c} (1.19)	24.44^{a} (0.67)	20.34^{b} (2.21)
Ester	Amyl isovalerate	apple fresh fruity	0.26 NS	0.05 (0.01)	0.04 (0.01)	0.05 (0.01)	0.22^{b} (0.04)
Ester	Nonanoic acid, ethyl ester (3000)	Waxy, cognac, estery, fruity apple and banana, tropical, winey, pineapple	9.06 **	27.56^{a} (5.97)	23.38^{ab} (1.92)	15.40^{c} (1.28)	1.84^{a} (0.07)
Ester	Decanoic acid, ethyl ester	sweet waxy fruity apple grape oily brandy, floral, banana-like, pineapple-like	19.03 ***	0.46^{a} (0.15)	0.37^{ab} (0.11)	ND	1.07^{b} (0.18)
Ester	10-Undecenoic acid, ethyl ester; Ethyl undecenoate	Fruit with wine, waxy and creamy shades	8.33 **	0.34^{ab} (0.12)	0.45^{a} (0.10)	0.19^{b} (0.02)	0.22^{b} (0.05)

Effect of variety on Volatile compounds detected in the beers of 2019 crop barley(cont'd)

Here listed:
13 Ester
20 Alcohol
7 Aldehyde
1 Acid
1 Amine
1 Alkane
1 Alkene

Chemical Class	Volatile	Odour	Source of Variation - F-values and Probability	Variety Mean Values (ug/L, ppb)			
				CDC Bow (n=3)	AAC Connect (n=4)	CDC Copeland (n=3)	Harrington (n=3)
Ester	Propanoic acid, 2-methyl-, 2-phenylethyl ester	Floral, fruity, rose, tea, peach, pastry, honey, yeasty, balsamic	8.19 **	8.00^{b} (0.70)	7.74^{b} (0.61)	10.27^{a} (1.38)	6.96^{b} (1.29)
Ester	Formic acid butyl ester (87)	fruity plum rum brandy	4.96 *	1431.35^{a} (99.01)?	785.88^{a} (533.95)?	1636.43^{a} (151.54)?	0.94^{b} (0.25)
Ester	Propyl acetate; propyl ethanoate (240)	solvent celery fruity fusel raspberry pear	8.86 **	318.15^{ab} (74.81)	229.55^{bc} (45.36)	368.63^{a} (18.06)	165.45^{c} (89.65)
Acid	Propanoic acid, 3-(methylthio	Meaty, onion, fruity (low concentration)	4.96 *	1.07^{ab} (0.34)	0.28^{b} (0.15)	0.84^{ab} (0.55)	1.35^{a} (0.64)
Alcohol	(+)-Humulenol II	Hop related flavour compound	8.81 **	0.37^{a} (0.06)	0.22^{b} (0.05)	0.19^{b} (0.07)	0.35^{a} (0.08)
Alcohol	1-Heptanol	Musty, pungent, leafy green, vegetative and fruity, apple and banana, violet, sweet, woody, peony, nutty	0.82 NS	0.78 (0.13)	0.76 (0.15)	0.98 (0.42)	0.78 (0.16)
Alcohol	L-terpinen-4-ol	Mild earthy and woody odor	10.10 ***	0.07^{b} (0.01)	0.07^{b} (0.01)	0.07^{b} (0.01)	18.96^{bc} (3.48)
Alcohol	Isoamyl acetate; 1-Butanol, 3-methyl-, acetate (1100)	sweet fruity banana solvent	6.68 **	593.00^{a} (274.59)	20.43^{b} (16.45)	339.45^{a} (300.47)	0.19 (0.07)
Alcohol	3-Pentanol	sweet herbal oily nutty	10.13 ***	102.21^{ab} (57.40)	0.34^{c} (0.17)	138.71^{a} (19.29)	0.02^{b} (0.04)
Alcohol	1-Hexanol (2500)	Green, herbaceous, woody, sweet, apple	9.21 **	353.94^{a} (38.13)	0.06^{b} (0.11)	201.09^{ab} (231.63)	280.33^{a} (75.39)
Alcohol	1-Octanol	Waxy, green, citrus, orange fruity, aldehydic and floral with a sweet, fatty, coconut nuance	0.99 NS	0.31 (0.05)	0.25 (0.05)	0.29 (0.13)	0.18^{a} (0.05)
Alcohol	2-Heptanol	fresh lemon grass herbal sweet floral fruity green	18.50 ***	0.28^{a} (0.02)	0.16^{c} (0.01)	0.20^{bc} (0.03)	0.25 (0.08)
Alcohol	2-Hexanol	winey fruity fatty terpenic cauliflower	3.26 NS	1.12 (0.35)	0.86 (0.52)	1.50 (0.78)	0.64^{c} (0.11)
Alcohol	1-Propanol, 2-methyl (Isobutyl Alcohol) (7000)	Whiskey, fusel oil, wine	0.41 NS	207.63 (189.79)	184.79 (130.05)	225.95 (161.75)	0.70 (0.13)

Effect of variety on Volatile compounds detected in the beers of 2019 crop barley (cont'd)

Chemical Class	Volatile	Odour	Source of Variation - F-values and Probability	Variety Mean Values (ug/L, ppb)			
				CDC Bow (n=3)	AAC Connect (n=4)	CDC Copeland (n=3)	Harrington (n=3)
Alcohol	4-Penten-2-ol, 4-methyl-	Pungent, fusel, cognac and wine, cocoa, with green fruity undernotes	2.27 NS	0.63 (0.15)	0.63 (0.28)	0.58 (0.09)	241.31 (136.65)
Alcohol	2-Furanmethanol, acetate	Fruity ethereal rummy caramel brown cooked cognac tequila caramellic nutty	5.59 **	1.19^{a} (0.30)	0.35^{b} (0.15)	0.60^{ab} (0.55)	1.16^{a} (0.47)
Alcohol	2-Butanol, 3-methyl-; Isoamyl alcohol	Fusel, alcoholic, pungent, etherial, cognac, fruity, banana and molasses	39.86 ***	1.25^{b} (0.23)	1.78^{a} (0.09)	0.94^{bc} (0.15)	0.50^{ab} (0.09)
Alcohol	1-Pentanol, 2-methyl-, acetate ; Acetic acid, 2-methylamyl ester		4.78 *	0.11^{ab} (0.10)	ND	0.18^{a} (0.14)	0.24^{ab} (0.03)
Alcohol	2-Heptanol-6 methyl		1.83 NS	0.68 (0.07)	0.68 (0.07)	0.89 (0.28)	0.36 (0.18)
Alcohol	2-Hexanol-3-methyl		3.18 NS	1.83 (0.22)	1.19 (0.14)	1.60 (0.54)	1.58 (0.36)
Alcohol	3-Buten-2-ol, 3-methyl-		5.90 **	1.09^{ab} (0.37)	1.30^{a} (0.15)	1.16^{a} (0.36)	0.41^{b} (0.15)
Alcohol	3-Heptanol, 5-methyl-		0.70 NS	0.95 (0.27)	0.70 (0.27)	1.11 (0.76)	0.05 (0.01)
Alcohol	3-Heptanol-4-methyl		0.88 NS	0.29 (0.04)	0.24 (0.02)	0.30 (0.09)	0.13 (0.03)
Alcohol	3-methyl-1-hexen-3-ol		0.07 NS	1.41 (0.13)	1.29 (0.14)	1.40 (1.02)	0.11 (0.11)
Aldehyde	Heptanal (3-30)	Sweet, fruity, nutty, green	0.63 NS	0.02 (0.02)	0.01 (0.02)	0.02 (0.02)	0.56^{b} (0.27)
Aldehyde	Hexanal-3-methyl	Sweet green	21.63 ***	1.46^{a} (0.15)	0.72^{c} (0.07)	1.24^{ab} (0.18)	0.34^{a} (0.12)
Aldehyde	2-Hexenal	sweet almond fruity green leafy apple plum vegetable	4.09 *	0.51^{ab} (0.05)	0.36^{b} (0.04)	0.54^{a} (0.14)	1.19^{a} (0.28)
Aldehyde	Isobutylaldehyde dimethyl acetal	Brandy, Pleasant, Fruity, Wine	3.80 *	0.22^{ab} (0.09)	0.08^{b} (0.10)	1.92^{a} (2.07)	0.29 (0.21)
Aldehyde	Benzeneacetaldehyde, α-ethyl-	Floral	108.87 ***	ND	ND	0.45^{a} (0.09)	ND
Aldehyde	Benzaldehyde (350-3500)	Almond	3.40 NS	0.13 (0.01)	0.13 (0.03)	0.17 (0.02)	0.69^{c} (0.16)
Aldehyde	Propanal, 2,3-dihydroxy-, (S)-		3.42 NS	2.06 (0.19)	0.71 (0.78)	2.15 (1.44)	1.80 (0.36)

Effects of G, E & G x E Interaction on Non-volatile compounds detected in beers of 2019 crop

Out of the **32** compounds detected:
21 showed significant variety effect;
8 showed significant location effect
1 showed significant G x E interaction.

Compound	Source of Variation - F-values and Probability			Variety Mean Values (mM) n=6				Location Mean Values (mM) n=8		
	Variety (G)	Location (E)	G x E	CDC Bow	AAC Connect	CDC Copeland	Harrington	Brandon	Lacombe	Saskatoon
Alcohols										
Glycerol	1.05 NS	0.46 NS	†	2.20 (0.20)	1.89 (0.35)	2.08 (0.48)	2.17 (0.22)	2.12 (0.32)	1.99 (0.46)	2.14 (0.21)
Carboxylic Acid										
4-Aminobutyrate	1.51 NS	0.71 NS	†	0.33 (0.04)	0.27 (0.08)	0.36 (0.12)	0.32 (0.02)	0.32 (0.13)	0.29 (0.03)	0.34 (0.04)
Fumarate	4.28 *	5.78 *	†	0.03a (0.00)	0.02b (0.01)	0.03b (0.00)	0.02b (0.00)	0.02b (0.01)	0.02b (0.00)	0.03a (0.00)
Lactate	4.21 *	34.07 ***	†	0.27a (0.12)	0.18b (0.07)	0.25ab (0.10)	0.26a (0.10)	0.21b (0.06)	0.16b (0.03)	0.35a (0.07)
Phenylacetate	2.21 NS	0.76 NS	†	0.19 (0.04)	0.14 (0.05)	0.20 (0.04)	0.20 (0.06)	0.18 (0.05)	0.17 (0.05)	0.20 (0.04)
Pyroglutamate	15.72 ***	0.68 NS	†	0.98a (0.04)	0.68b (0.12)	0.94a (0.05)	1.06a (0.13)	0.91 (0.22)	0.91 (0.13)	0.93 (0.16)
Pyruvate	7.26 **	4.59 *	†	0.99a (0.07)	0.77b (0.18)	0.97a (0.13)	1.01a (0.03)	0.85b (0.17)	1.00a (0.14)	0.96ab (0.09)

Effects of G & E & G x E Interaction on Non-volatile compounds detected in beers of 2019 crop (cont'd)

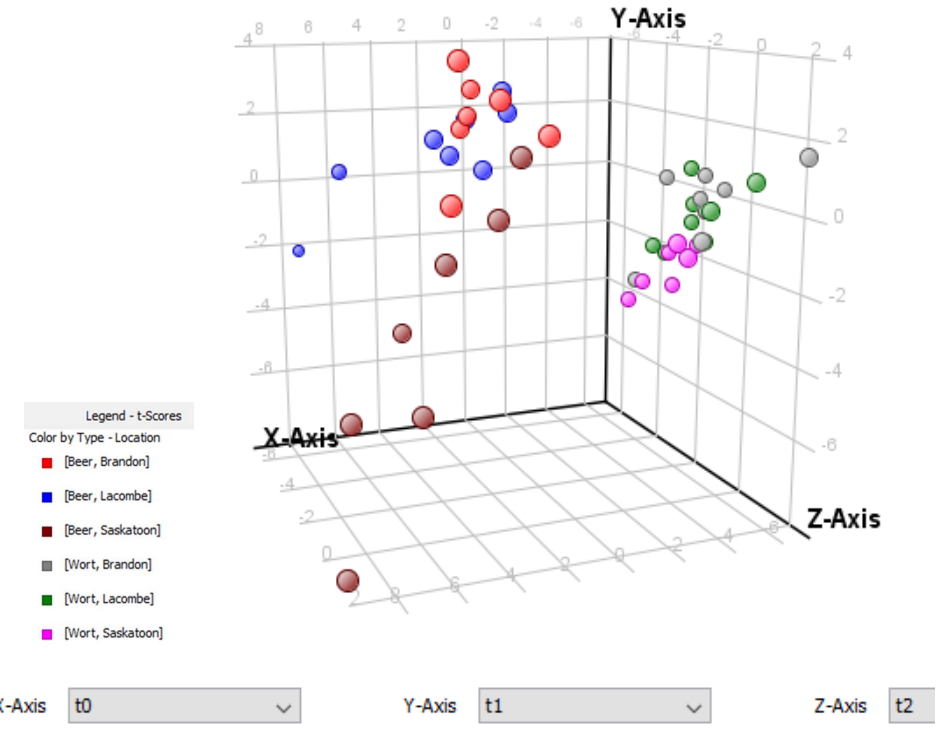
Out of the 32 compounds detected, 21 showed significant variety effect; 8 showed significant location effect and 1 showed significant G x E interaction.

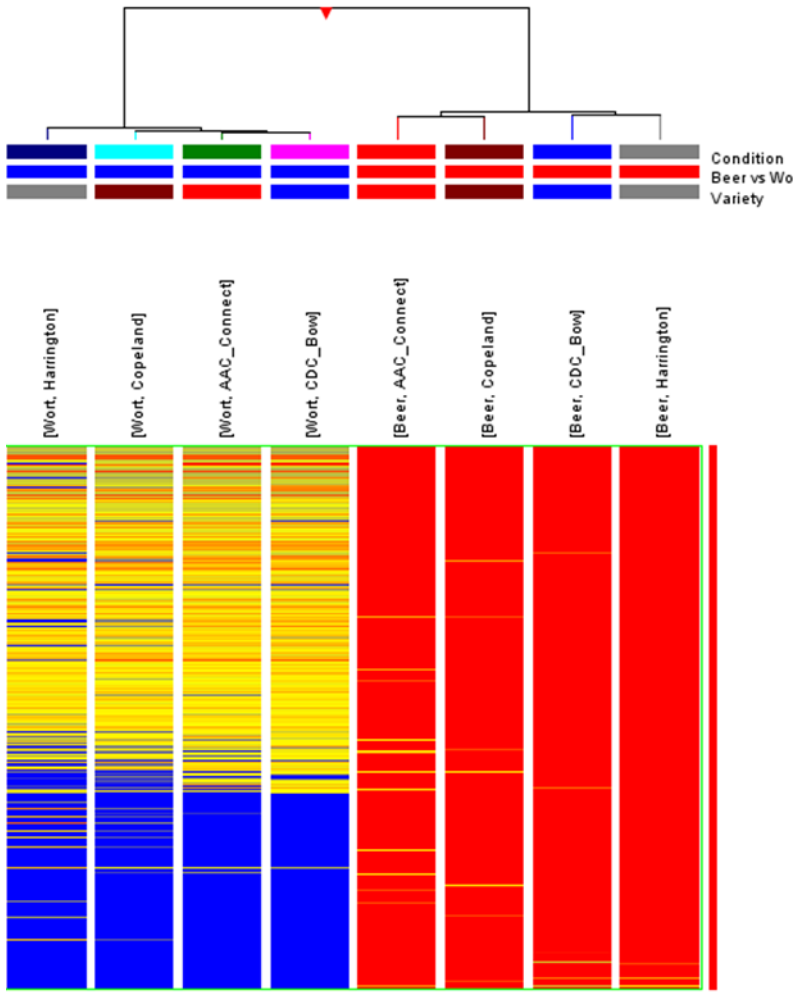
Compound	Source of Variation - F-values and Probability			Variety Mean Values (mM) n=6				Location Mean Values (mM) n=8		
	Variety (G)	Location (E)	G x E	CDC Bow	AAC Connect	CDC Copeland	Harrington	Brandon	Lacombe	Saskatoon
Amino Acids										
Alanine	5.97 **	0.47 NS	†	0.69[a] (0.12)	0.39[b] (0.15)	0.58[ab] (0.15)	0.66[a] (0.11)	0.57 (0.17)	0.61 (0.15)	0.55 (0.21)
Betaine	7.61 **	2.66 NS	†	0.45bc (0.06)	0.40c (0.09)	0.57a (0.07)	0.50ab (0.05)	0.52 (0.12)	0.44 (0.08)	0.48 (0.04)
Isoleucine	10.16 ***	1.56 NS	†	0.22a (0.05)	0.08c (0.04)	0.13bc (0.05)	0.20ab (0.05)	0.17 (0.07)	0.17 (0.07)	0.13 (0.08)
Leucine	8.12 **	0.89 NS	†	0.37a (0.08)	0.15c (0.05)	0.21bc (0.09)	0.32ab (0.10)	0.28 (0.13)	0.29 (0.12)	0.24 (0.12)
Lysine	11.41 ***	0.67 NS	†	0.16a (0.02)	0.09b (0.03)	0.14a (0.02)	0.16a (0.03)	0.14 (0.04)	0.13 (0.03)	0.13 (0.04)
Phenylalanine	9.36 ***	4.95 *	†	0.38a (0.06)	0.19b (0.09)	0.28ab (0.10)	0.34a (0.05)	0.31ab (0.10)	0.33a (0.08)	0.23b (0.11)
Proline	7.75 **	2.72 NS	†	2.65a (0.16)	1.85b (0.44)	2.72a (0.76)	2.96a (0.19)	2.68 (0.68)	2.69 (0.54)	2.26 (0.55)
Tryptophan	8.55 **	25.66 ***	†	0.11a (0.03)	0.08b (0.03)	0.11a (0.04)	0.13a 0.04)	0.15a (0.03)	0.09b (0.02)	0.09b (0.03)
Tyrosine	7.55 **	1.58 NS	†	0.37a (0.05)	0.23b (0.07)	0.34a (0.07)	0.36a (0.05)	0.35 (0.10)	0.33 (0.07)	0.30 (0.08)
Valine	9.79 ***	1.70 NS	†	0.55a (0.06)	0.30b (0.13)	0.44ab (0.10)	0.55a (0.06)	0.49a (0.14)	0.48a (0.11)	0.41b (0.15)

Effects of G & E & G x E Interaction on non-volatile compounds detected in beers of 2019 crop (cont'd)

Lipids										
O-Phosphocholine	6.48 **	15.37 ***	†	0.31^{a} (0.09)	0.25^{ab} (0.06)	0.21^{b} (0.07)	0.21^{b} (0.05)	0.24^{b} (0.07)	0.31^{a} (0.05)	0.19^{b} (0.05)
Nucelotides, nucleosides and bases										
2'-Deoxyadenosine	3.22 *	0.59 NS	†	0.15^{ab} (0.01)	0.13^{b} (0.03)	0.17^{a} (0.03)	0.15^{ab} (0.01)	0.15 (0.04)	0.14 (0.02)	0.16 (0.03)
2'-Deoxyguanosine	3.21 NS	0.25 NS	†	0.05 (0.01)	0.04 (0.01)	0.05 (0.01)	0.04 (0.00)	0.04 (0.01)	0.04 (0.01)	0.04 (0.01)
Adenosine	7.43 **	8.58 **	†	0.06^{a} (0.01)	0.04^{b} (0.01)	0.06^{a} (0.01)	0.06^{a} (0.01)	0.05^{ab} (0.01)	0.06^{a} (0.01)	0.05^{b} (0.01)
Cytidine	2.54 NS	15.70 ***	7.67 **	0.11 (0.03)	0.09 (0.02)	0.11 (0.02)	0.11 (0.03)	0.11a (0.02)	0.11a (0.02)	0.08b (0.02)
Guanosine	1.53 NS	0.13 NS	†	0.13 (0.01)	0.11 (0.02)	0.13 (0.02)	0.13 (0.01)	0.13 (0.02)	0.13 (0.02)	0.13 (0.01)
Thymidine	2.07 NS	2.48 NS	†	0.04 (0.01)	0.03 (0.01)	0.04 (0.01)	0.04 (0.01)	0.03 (0.01)	0.03 (0.01)	0.04 (0.01)
Uridine	2.37 NS	1.94 NS	†	0.13 (0.01)	0.10 (0.03)	0.11 (0.02)	0.12 (0.01)	0.11 (0.02)	0.11 (0.02)	0.12 (0.02)
Sugars										
1,6-Anhydro-β-D-glucose	6.27 **	3.38 NS	†	0.29a (0.04)	0.18b (0.05)	0.21b (0.07)	0.21b (0.01)	0.21 (0.04)	0.25 (0.06)	0.20 (0.07)
Cellobiose	1.92 NS	3.58 NS	†	0.47 (0.07)	0.34 (0.11)	0.48 (0.19)	0.44 (0.13)	0.47 (0.08)	0.49 (0.17)	0.34 (0.11)
Glucose	6.58 **	1.71 NS	†	0.48^{b} (0.11)	0.39^{b} (0.14)	1.66^{a} (1.22)	0.36^{b} (0.10)	0.84 (1.01)	0.92 (0.95)	0.41 (0.12)
Maltose	2.98 NS	1.35 NS	†	3.95 (0.40)	3.15 (0.64)	3.12 (1.68)	4.44 (0.26)	3.24 (1.04)	3.97 (1.14)	3.78 (0.92)
Xylose	10.78 ***	1.79 NS	†	0.51bc (0.10)	0.35c (0.09)	0.71a (0.19)	0.63ab (0.05)	0.56a (0.22)	0.60a (0.19)	0.49b (0.11)
Vitamins										
Choline	10.12 ***	1.31 NS	†	0.55bc (0.05)	0.45c (0.12)	0.68a (0.08)	0.61ab (0.04)	0.57 (0.15)	0.54 (0.10)	0.60 (0.09)
Pyridoxine	0.91 NS	0.31 NS	†	0.01 (0.00)	0.01 (0.01)	0.02 (0.01)	0.01 (0.00)	0.01 (0.00)	0.01 (0.01)	0.01 (0.00)

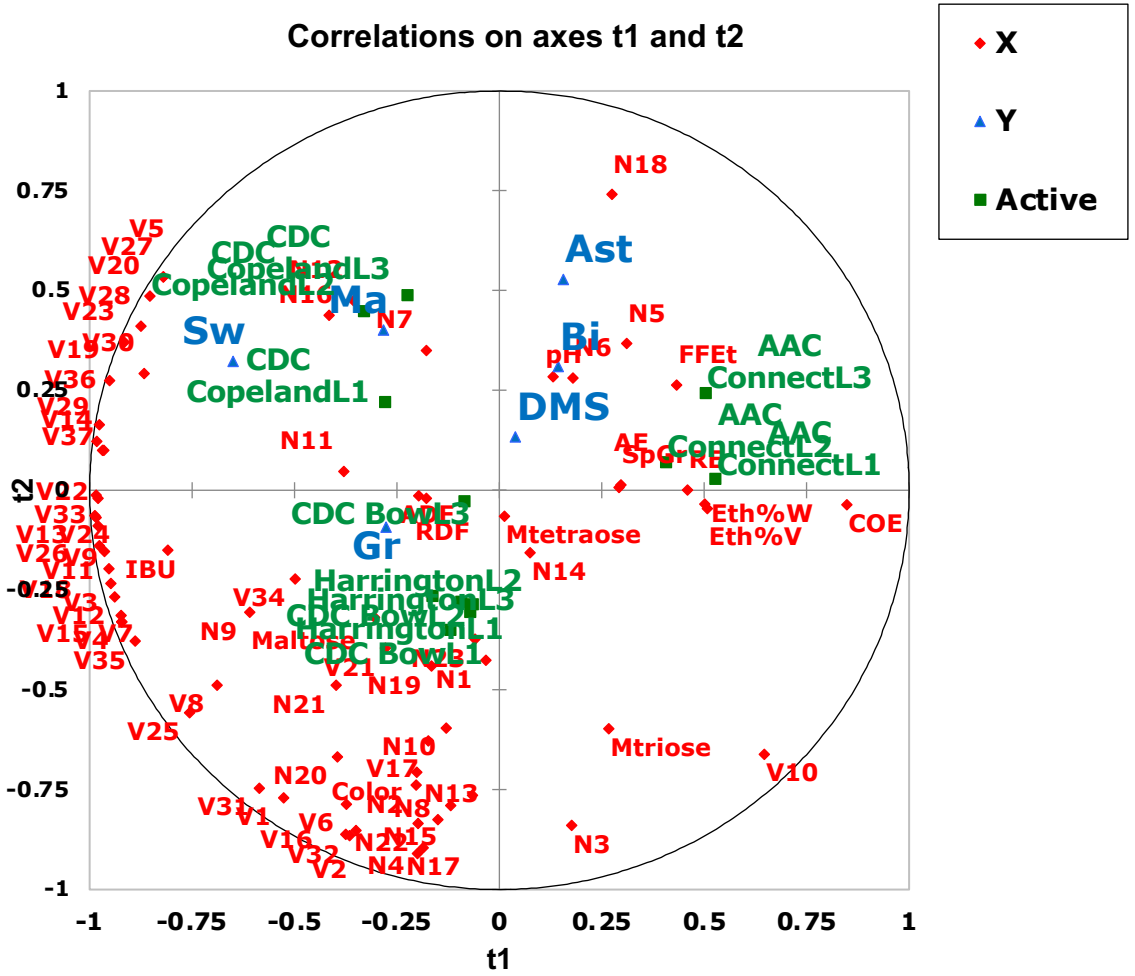
In 2018 crop samples, a clear separation between beer and wort (Figure 1), as well as some special differences between growing locations, was observed using PCA analysis based on the 180 water-soluble, untargeted non-volatile compounds detected by the LC-QTOF.





In 2019 crop samples Hierarchical Clustering Analysis of beer and wort compounds (n = 480) detected by LC-QTOF-MS

Partial Least Square Discrimination Analysis (PLS-DA)



- *Isopentyl acetate: (Fruity Aroma)*
- *Alpha Calacorene: (Woody)*
- *Ethyl decanoate: (Sweet, Apple)*
- *Specific Gravity*
- *IBU*
- *Apparent extract*
- *Hop Flavour*

Abbreviations for Volatiles

1-Butanol-3-Methyl acetate (**ButMA**)
Ethyl decanoate (**EtDec**)
Alpha Calacorene (**Acal**)
Hexanoic acide (**HexAc**)
Benzene-3 methylbutyl (**BenMB**)
Octanoic acid (**OctAc**)
Carvacrol [(Phenol, 2-methyl-5-(1-ethylmethyl)] - Car
Butylated hydroxytoluene (**ButHT**)
Murrorul (**Mur**)
Cadinol (**Cad**)

Conclusions

- Barley variety, growing location and their interactions showed significant impacts on the beer's overall quality.

- Variety and location showed limited influence on the nine sensory attributes evaluated in this study. Out of these attributes, only acetaldehyde showed significant varietal difference. Its level in CDC Copeland beer was significantly higher than that in Harrington beer. This might suggest that the four barley varieties evaluated in this study are relatively close to each other in terms of sensory properties. Of course, this is did not take into account the differences in other sensory attributes that were not assessed in this study.

- Variety and location showed significant influence on the flavor compounds detected in beers by GC-MS.

Conclusions

- Some of the underlying organic compounds in wort and beer that are linked to specific sensory attributes have been identified for AAC Connect, CDC Bow, CDC Copeland and Harrington barley. It is evident that variety and growing location had significant influence on these organic compounds.

- The results demonstrated that the effects of variety and growing location can carry through the malting and brewing process to impact a beer's flavor attributes in terms of beer sensory and the underlying organic compounds.

- In addition to the barley varietal effect on beer flavor, the barley's "terroir" effect on beer flavor should be considered as well. Quality of finished malt is determined from the interaction of the barley grain and the processing conditions applied, while raw barley grain quality is determined by barley's genetic potential and the growing conditions (weather, soil and farming practice) the barley was subjected to prior to harvesting.

Acknowledgments

Funding from:

Government of Canada under the Canadian Agricultural Partnership's AgriScience Program, a federal, provincial, and territorial initiative

Canadian barley industry funders Saskatchewan Barley Development Commission, the Brewing and Malting Barley Research Institute and the Canadian Malting Barley Technical Center.

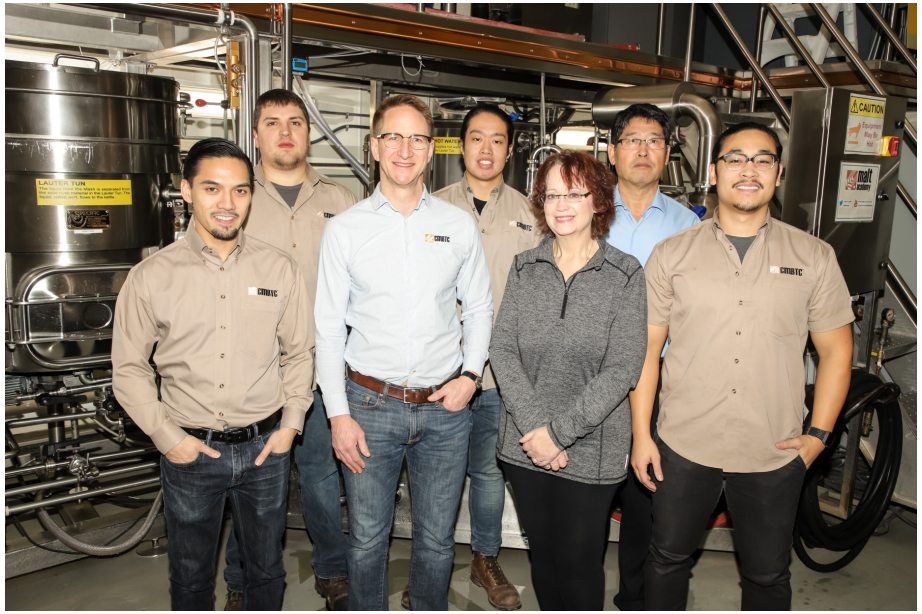
Acknowledgments

Dr. Michel Aliani and Donna Ryland at University of Manitoba

Dr. Aaron Beattie's team at University of Saskatchewan

Dr. Ana Badea's team at AAFC Brandon Research and development Centre

Dr. Flavio Capettini's team at Field Crop development centre, Olds College



The CMBTC Team

Cheers!!!

Yueshu Li
yli@cmbtc.com


Q&A