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Hop creep variability unveiled: a comparative analysis of hop variety, quantity, origin, and product type

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Abstract

Why was the work done: Hop creep remains a challenge for breweries producing dry hopped beers, as it leads to secondary fermentation that affects both beer quality and safety. Therefore, it is valuable to analyse hop creep across hop product types, growing regions, varieties, and concentrations to establish baseline metrics that reduce batch-to-batch uncertainty for brewers.

How was the work done: This study investigated the role of hop product types, growing regions, varieties, and extent of hop creep in laboratory fermentations. Over 450 fermentations were performed, spanning five hop product formats (T90, Cryo, whole leaf, Noble, and enriched polyphenol aroma pellets/EPAP), six growing regions, and 19 hop varieties. Hops were added at 1 g or 2 g per 100 mL (1 or 2 kg/hL) of beer, reflecting industry usage. Samples were analysed in R with multi-way ANOVA and Tukey post-hoc analysis.

What are the main findings: Significant ($p < 0.05$) differences were observed between hop varieties, origins, and product types, highlighting their role in hop creep. However, no significant difference was found with the amount of hops added. Widely used hop varieties, product types, and growing regions showed similar levels of hop creep.

Why is the work important: While the phenomenon of hop creep requires further investigation, these results provide insight to anticipate hop creep by hop variety, product type, and origin. This will help improve the consistency, beer quality, and safety of dry-hopped styles.

Keywords

Beer, hops, *Humulus lupulus*, hop variety, dry hopping, hop creep, fermentation

Introduction

'Hop creep' is the unintended secondary fermentation of beer (Kirkpatrick and Shellhammer 2018). The first report that enzymes associated with hops were responsible for secondary fermentation was made in the 19th century in the UK with cask beer (Brown and Morris 1893). Today, this phenomenon poses challenges in managing product quality in breweries where hops are added to cold beer; a process known as 'dry hopping'. Hop forward beer styles including Belgian beers (Silva Ferreira et al. 2018) and, more widely, IPA styles such as Pale Ales, India Pale Ales (IPAs), Double or Triple IPAs (DIPAs/TIPAs), and New England IPAs (NEIPAs) (Beer Judge Certification Program 2021).

Hop creep by amylolytic enzymes contributes negative sensory and quality attributes to beer. These include the formation of diacetyl, increased carbon dioxide and ethanol, together with decreased content of dextrins which impacts on mouthfeel resulting in unbalanced flavour and aroma (Werrie et al. 2022; Klimczak et al. 2023). Additionally, fermentation cycle time and attenuation are inconsistent varying between batches, despite using the same recipe (Hrabia et al. 2024). The implications of hop creep are concern for product quality and safety. Diacetyl, a compound with a strong butter-like aroma (Krogerus and Gibson 2013), is produced by yeast during secondary fermentation through hop creep. Increased alcohol levels can result in beer being out of specification and elevated CO_2 levels can result in cans peaking, or worse, exploding!

Current methods for managing hop creep rely on brewhouse or cellaring workarounds and trial and error (Young 2021). Previous work has quantified the enzymic activity in hops; however, translation into practical application has proven challenging, particularly when hop varieties, formats, and usage rates differ from those used in brewing practice (Kirkpatrick and Shellhammer 2018a). More recently, studies confirmed the existence of starch degrading enzymes (Teraoka et al. 2021; Young et al. 2023; Cottrell 2025).

Kirkpatrick and Shellhammer (2018b) evaluated the enzymic potential of 30 hop varieties by incubating in beer for 24 hours and measuring changes in sugar composition. The findings demonstrated that hops contain enzymes that break down dextrins. However, enzymatic activity alone does not predict fermentation outcomes, especially as the levels of non-fermentable dextrins in wort can vary in beers.

The objective of this study was to provide translatable data based on secondary fermentation by hops with measurement of changes in ABV (alcohol by volume). As breweries have different dry hopping procedures, timing of additions and wort composition, the experiments used a consistent approach to dry hopping and beer composition, with the sole variable being the type of hop. This approach enabled comparison of hop creep against hop product, quantities, variety, and growing region.

Materials and methods

Hops

Hops were donated from Yakima Chief Hops, Yakima, Washington and Hop Head Farms LLC, Hickory Corners, Michigan. Hop variety, format and year of harvest are reported in Table 1.

Secondary fermentation

Saccharomyces cerevisiae (0.3 g active dried yeast - Fermentis S05) and hops (1 g or 2 g) were added to American Golden Lager (100 mL) in Erlenmeyer flasks (250 mL) and incubated with stirring (100 rpm) for seven days. The beer had an ABV of 5.3% ± 0.03, a density of 1.0050 ± 0.0005, and a real extract of 3.55 ± 0.05. The beer was selected due to its known dextrin concentration and product consistency (Vollmer and Shellhammer 2016; Kirkpatrick 2018). Rates of hop addition were chosen to reflect common industry practice with 1 g/100 mL corresponding to 1 kg/hL and 2 g/100 mL corresponding to 2 kg/hL. Details of yeast, beer and hops are reported in Table 2.

Sample collection and analysis

Samples were centrifuged at 2500 × g for 5 minutes and the ABV and density measured (Anton Paar Alcolyzer DMA 5000, Austria) (Bruner et al. 2021; 2020). All treatments were in triplicate with approximately 12 fermentations per week, enabling statistical analysis across hop samples. Although a

Table 1.

Hop variety, product type, supplier, growing region, and year of harvest.

Hop Variety	Product Type	Supplier	Growing Region	Year
Citra	T90 pellets	HHF	Pacific Northwest	2021
Citra	T90 pellets, Cryo, EPAP, Whole leaf	YCH	Pacific Northwest	2021
Simcoe	T90 pellets, Cryo, EPAP, Whole leaf	YCH	Pacific Northwest	2021
Mosaic	T90 pellets	HHF	Pacific Northwest	2021
Mosaic	T90 pellets, Cryo, EPAP, Whole leaf	YCH	Pacific Northwest	
Cascade	T90 pellets, Cryo, Whole leaf	YCH	Pacific Northwest	2021
Cascade	T90 pellets	HHF	Michigan	2020/2021
Nelson Sauvin	T90 pellets	HHF	New Zealand	2021
Southern Passion	T90 pellets	HHF	South Africa	2021
French Aramis	T90 pellets	HHF	France	2020
Hallertau Blanc	T90 pellets	HHF	Germany	2021
El Dorado	T90 pellets	HHF	Pacific Northwest	2021
Sabro	T90 pellets	HHF	Pacific Northwest	2021
Styrian Wolf	T90 pellets	HHF	Slovenia	2021
Galaxy	T90 pellets	HHF	Australia	2021
Centennial	T90 pellets	HHF	Michigan	2020/2021
Strata	T90 pellets	HHF	Pacific Northwest	2020
Hallertau Mittelfrüh*	T90 pellets	HHF	Germany	2021
Motueka	T90 pellets	HHF	New Zealand	2021
Perle	T90 pellets	HHF	Germany	2021
Vic Secret	T90 pellets	HHF	Australia	2021
Czech Saaz*	T90 pellets	HHF	Czech Republic	2021
Mandarina Bavaria	T90 pellets	HHF	Germany	2021
African Queen	T90 pellets	HHF	South Africa	2021

Hops were sourced from Yakima Chief (YCH) or Hop Head Farms (HHF). EPAP - enriched polyphenol aroma pellets.
* Noble hops.

range of hop formats were tested, the dataset is imbalanced, with most samples being pelletised hops from the Pacific Northwest (Table 1). Although the full dataset contains an uneven distribution of hop types and regions, statistical analyses was performed separately within each category. This stratified approach helps minimise the potential impact of data imbalance on interpretation of the results.

Statistics

Data was captured using Microsoft Excel and analysed in R Studio. A fixed-effects analysis of variance (ANOVA) was used to assess the impact of hop quantity, product type, variety, and growing region on the increase in ABV due to hop creep. A p-value of <0.05 was considered statistically significant. Tukey's post-hoc test was used to identify

Table 2.

Yeast, beer, and hops.

Product	Type	Storage	Notes
Saccharomyces cerevisiae	Fermentis S05	4°C for six months	Vacuum sealed
Beer	American Golden Lager	4°C for three months	5 ± 0.2% ABV
Hops	Various YCH, Hop Head Farms	4°C for six months	Mylar bags and vacuum sealed

Table 3.

Multi-way ANOVA showing F-values and significance levels for factors influencing hop creep: growing region, variety and product type.

Factor	Degrees of Freedom	F Values	P-Values
Growing region	5	5.524	8.97 x e^{-05} ***
Variety	18	4.234	5.25 x e^{-07} ***
Product type	4	4.654	0.001318**

Significance: $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***).

specific group differences, with letters denoting statistically separate groupings. Each factor was first evaluated individually, followed by a multifactor ANOVA to test for interactions. In the groupings, Group A represents the highest increase in ABV, B and C indicating progressively lower hop creep.

Results

The results of this work highlight key factors influencing hop creep. Significant effects were found for hop variety, product type, and growing region (Table 3), but not for hop quantity. Hop product type, growing region, and variety were all significant contributors to hop creep, with F and p-values of 4.654 ($p = 0.001318$), 5.524 ($p = 8.97 \times 10^{-5}$), and 4.234 ($p = 5.25 \times 10^{-7}$) (Table 3). Hop quantity – either 1 or 2 g/100 mL (equivalent to 1 or 2 kg/hL) - was not statistically significant ($p = 0.591$), with (respective) increases in mean ABV of 1.05 ± 0.07% and 0.978 ± 0.073%.

Table 4 reports the least square means and standard errors for hop product types and quantity. For additions of 1g/100 mL (1 kg/hL), T90 pellets had a mean ABV increase of 0.916 ± 0.033% and the lowest standard error of the mean. This suggests hop creep with T90 pellets was more consistent and reproducible across the trials, compared to Cryo (ABV 1.050 ± 0.070%), EPAP (0.935 ± 0.096%), Noble (0.915 ± 0.136%), and Whole Leaf hops (0.571 ± 0.096%). A similar result was found with hop additions of 2g/100 mL (2 kg/hL) with T90 pellets showing greater consistency (0.901 ± 0.033%) than other formats (Table 4).

Tukey post-hoc groupings (Figures 1–3), present hop creep by increase in ABV, with Group A showing the greatest increase, Group B intermediate, and Group C the lowest. Figure 1 shows distinct groupings of product types, Figure 2 the influence of growing regions, and Figure 3 shows hop varieties, with most clustering centrally with a few outliers displaying high or low increases in ABV.

Table 4.

Least square means and standard errors for the increase in ABV by product type and quantity.

Category	Least Square Mean (% ABV)	Standard Error
Cryo 1g	1.050	0.070
EPAP 1g	0.935	0.096
Noble1g	0.915	0.136
T90 1g	0.916	**0.033**
Whole leaf 1g	0.571	0.096
Cryo 2g	0.978	0.073
EPAP 2g	0.879	0.103
Noble 2g	1.053	0.136
T90 2g	0.901	**0.033**

Figure 1.

Product types - Cryo, T90, whole leaf, and enriched polyphenol pellets (EPAP) - based on Tukey post-hoc analysis groupings.

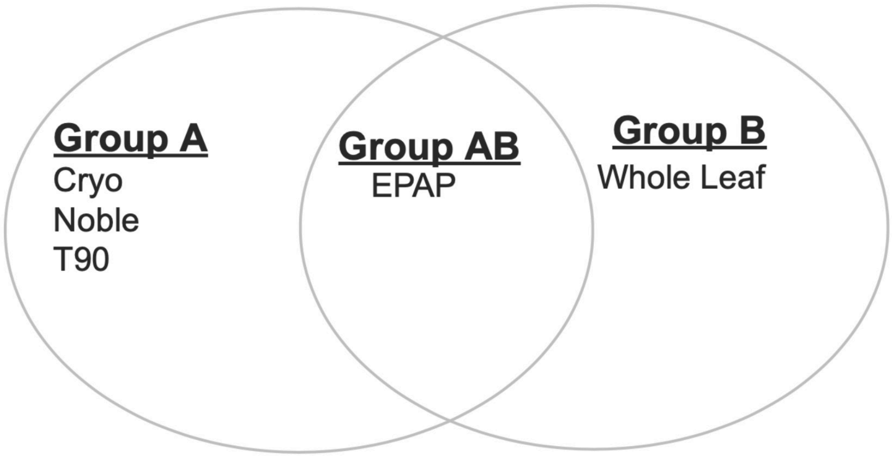


Figure 2.

Tukey post-hoc analysis groupings of growing regions and influence on hop creep: West Europe, Central Europe, Midwest, Pacific Northwest (PNW), South Africa, South Pacific.

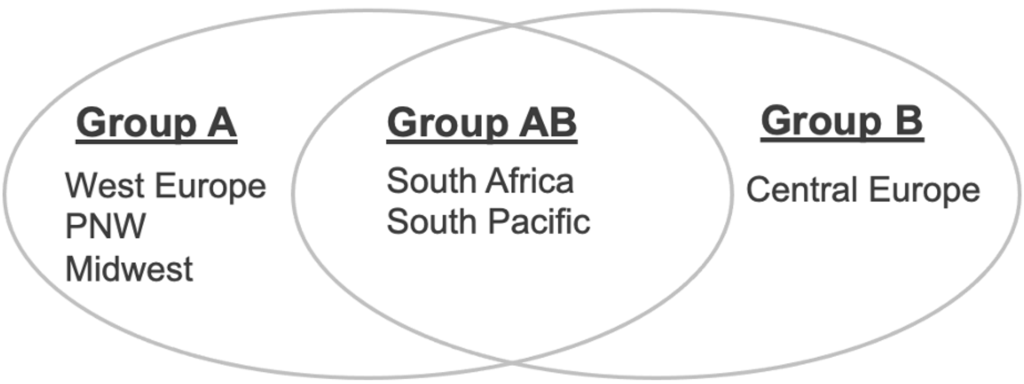


Figure 3.

Tukey post-hoc analysis groupings based on hop varieties.

Most hop varieties are in the groups ABC and BC.

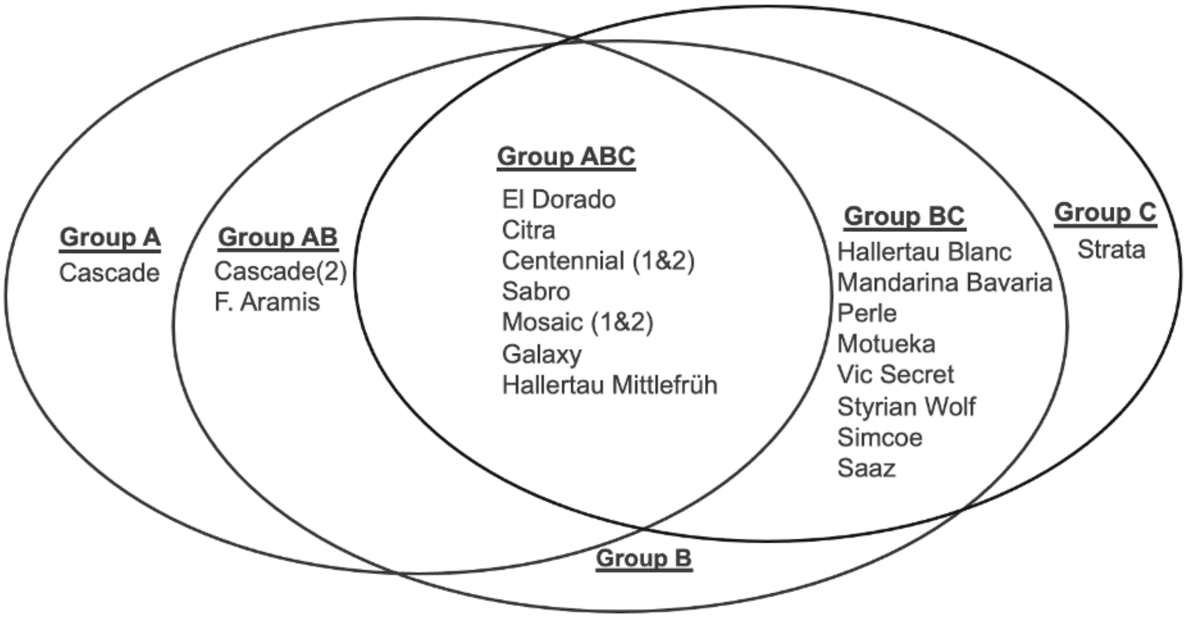


Figure 4.

Quantity of hops versus product type.

Hops added at 1g/100 mL beer (blue) and 2g/100 mL beer (grey) .

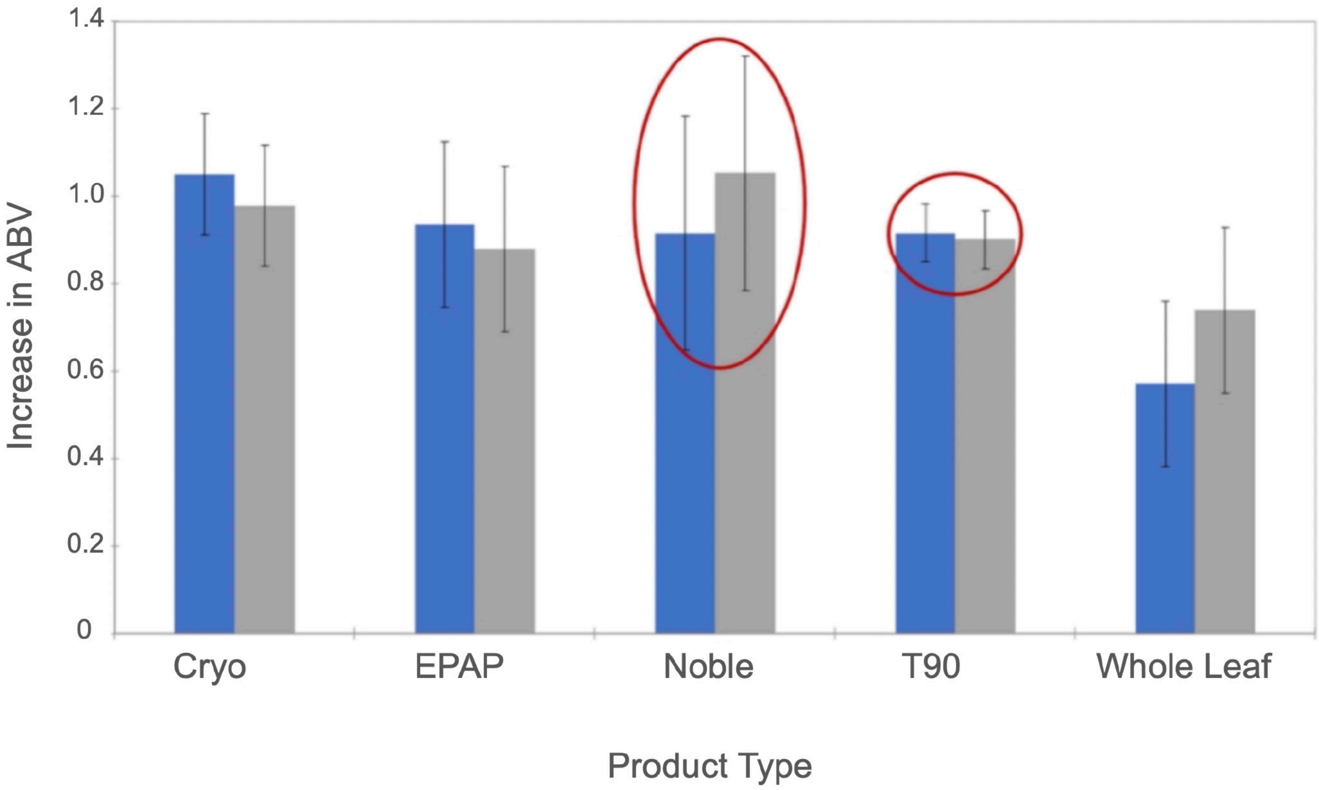


Figure 4 shows the impact on hop creep of the quantity of hops added and of the product format. As noted in Table 4, T90 hop pellets and 'cryo' were more consistent than the other formats suggesting they offer a more predictable hop creep. Similarly, Figure 5 shows the impact of product type on alcohol increase ($p < 0.05$), with T90 pellets the highest and whole leaf the least. Figure 6 expands the data in Figure 3, showing the increase in ABV varied significantly among the individual hop varieties ($p < 0.05$). Mean values (indicated by white diamonds) generally trended higher in hop varieties such as Cascade and Citra.

Figure 5.

Increase in alcohol by hop product type.

Boxplots display the distribution of the increase in ABV for each product type (with white diamonds showing mean value). Notably, T90 pellets had the highest, but most consistent mean increase in ABV as seen in Table 4. ANOVA confirmed a significant effect of product type ($p < 0.05$).

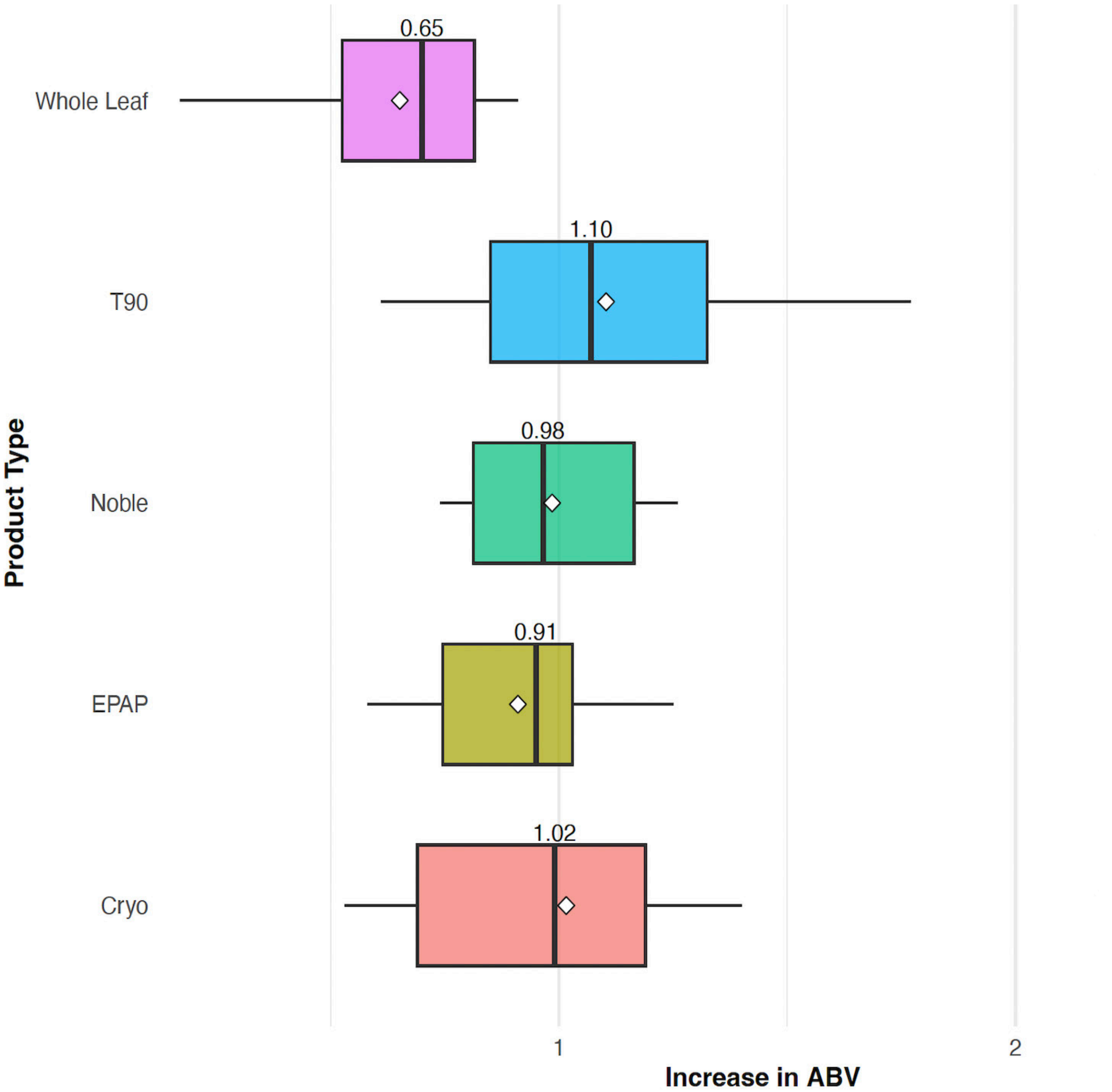
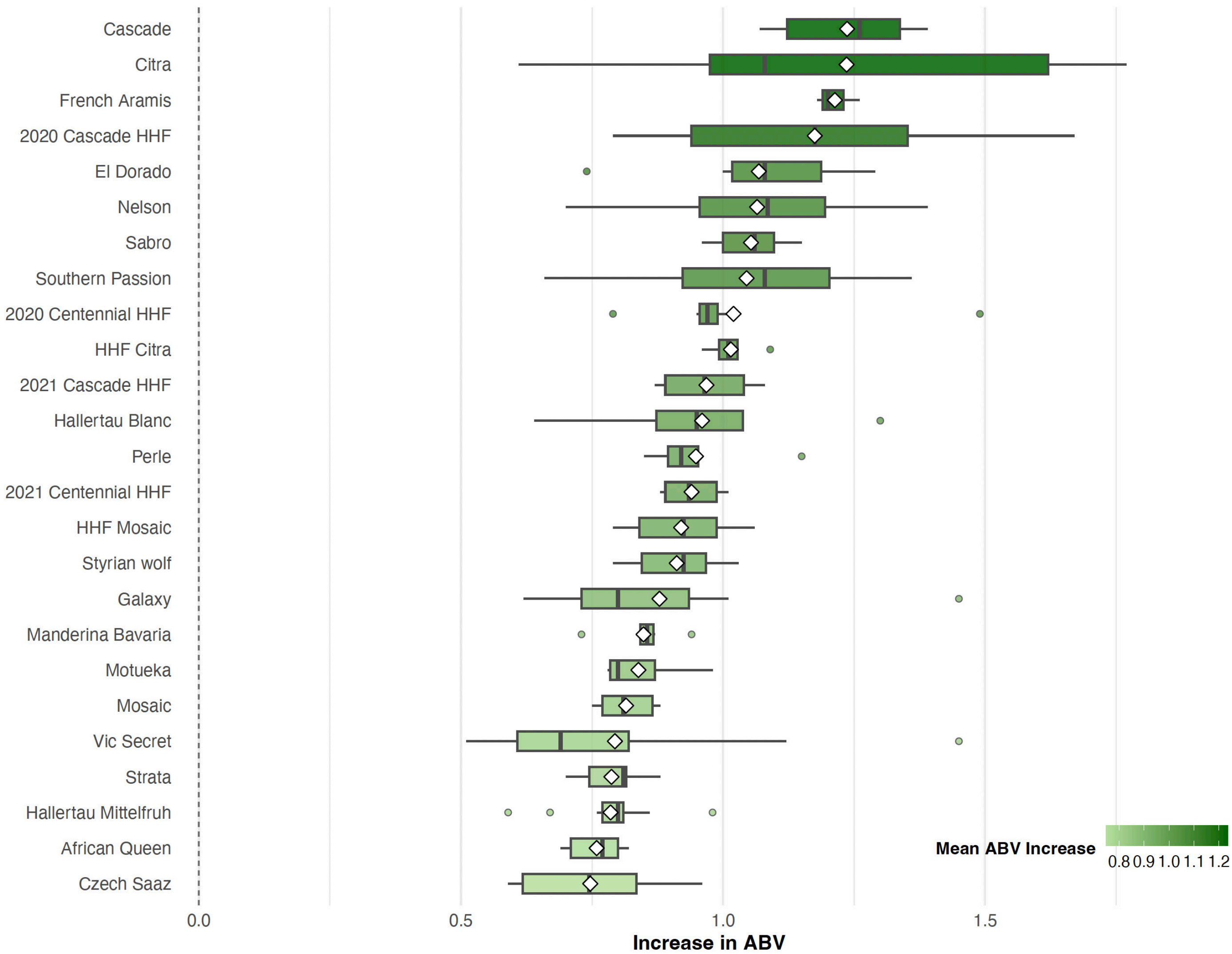


Figure 6.

Alcohol increase (ABV) by hop variety.

Boxplots show the distribution of the increase in ABV (with white diamonds indicating mean values). Varieties toward the top of the plot (e.g., Cascade, Citra) gtypically produced higher increases in mean ABV, with colour intensity reflecting this trend. ANOVA indicated a significant effect of variety on increase in ABV ($p < 0.05$).



Discussion

Understanding hop creep remains a challenge but the use of statistical analysis reveals significant trends. Factors such as growing region, product type, and hop variety exhibited statistically significant differences within each category (p-value <0.05). The Tukey post-hoc analysis grouped hops from the Pacific Northwest (PNW) and South Pacific together, revealing no significant difference between them, but both were significantly different from Central Europe. This grouping suggests that hops from the PNW and South Pacific, frequently used for dry hopping, contribute similar hop creep (Figure 2).

Central European hop varieties exhibited less creep, but this is less significant, with the unlikely use of Nobel dry hops (Saaz, Hallertau Mittelfrüh) in IPA recipes. Additionally, a recent report from Willemart et al (2025) found that contact time, temperature, and ethanol content significantly affected hop creep. Similarly, within product types, T90 and Cryo are grouped together in group A, while only whole leaf hops were in group B (Figure 1). This grouping suggests T90 and Cryo - two of the most used dry hop products - produce similar hop creep. Figure 4 and Table 4 reinforce this with the observation that Noble hops with larger error bars are likely to exhibit greater batch to batch variation.

In terms of the quantity of hops, there was no significant difference in ABV increase with dry hopping at (the equivalent of) 1 or 2 kg/hL. The lack of proportionality suggests other factors may be at play. Recent work on starch in hop cones (Young and Fox 2025) suggest that amylolytic enzymes may not be the only factor in hop creep, as starch could also contribute to the increased fermentation from hops.

The clustering of hop varieties in Figure 3 - near the centre of a normal distribution curve - suggests that moderate levels of hop creep are common. While environmental conditions and genetic variation are likely to contribute to year-to-year differences, the consistency of hop creep observed in consecutive years for Cascade and Centennial, as well as across two growing regions for Mosaic, suggests varietal or regional predictability. These findings support the need for further investigation into the genetic and agronomic factors that may influence hop creep. This aligns with the report of Wietstock et al (2025), who reported varietal and crop year differences in diastatic enzyme activity among German hop cultivars and between cone parts. This reinforces the view that genetic and agronomic factors influence hop creep. Further insight comes from Jobe et al (2024) who measured enzymatic activity in Cascade and Mosaic hops, with Cascade having the higher activity and, as in this study, showing the greatest hop creep.

Conclusions

The most important takeaway from the work reported here is that all product types, all varieties, and all growing regions, at any quantity, exhibit hop creep. Accordingly, breweries cannot prevent unintended secondary fermentation from dry hopping with all varieties contributing to hop creep, albeit to varying degrees.

Although statistically significant differences were found among growing regions, product types, and varieties, the hop products commonly used within each category often exhibit the same groupings. For example, IPAs are rarely brewed with whole leaf Czech Saaz hops, and are typically made using Nelson T90 or Citra Cryo, which both fall into the same hop creep Tukey Group (Figure 1).

Hop creep is a complex and multifaceted phenomenon. This study identifies three factors - growing region, product type, and variety - that influence hop creep which may help brewers reduce uncertainty. Nevertheless, many of the underlying dynamics remain poorly understood and warrant further work to clarify the mechanisms involved.

Author Contributions

Jessica Young: Conceptualisation, methodology, software, validation, formal analysis, investigation, data curation, writing (original draft), visualisation.
Glen Fox: Resources, supervision, project administration, funding acquisition.

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References

Beer Judge Certification Program. 2021. BJCP beer style guidelines. https://www.bjcp.org/beer-styles/beer-style-guidelines/

Brown HT, Morris G H. 1893. On certain functions of hops used in the dry-hopping of beers. *Brew Guard* 23:93-94, 107-109. https://www.google.co.uk/books/edition/_/MsI9AQAAMAAJ?hl=en&gbpv=1

Bruner J, Marcus A, Fox G. 2021. Dry-hop creep potential of various *Saccharomyces* yeast species and strains. *Fermentation* 7:66. https://doi.org/10.3390/fermentation7020066

Bruner J, Williams J, Fox G. 2020. Further exploration of hop creep variability with *Humulus lupulus* cultivars and proposed method for determination of secondary fermentation. *Tech Q Master Brew Assoc Am* 57:1002–1008. https://doi.org/10.1094/tq-57-3-1002-01

Cottrell M. 2025. Contribution of β-amylase from hops to the fermentability of dry hopped beer. *J Inst Brew* 131:92-99. https://jib.cibd.org.uk/index.php/jib/article/view/75

Hrabia O, Poręba P, Ciosek A, Poreda A. 2024. Effect of dry hopping conditions on the hop creep potential of beer. *J Am Soc Brew Chem* 82:412–421. https://doi.org/10.1080/03610470.2024.2388430

Jobe C, Féchir M, Rubottom L, Shellhammer TH. 2024. The importance of variety and regional identity on the dextrin-reducing enzymatic activity of Cascade and Mosaic hops grown in Washington and Oregon. *J Am Soc Brew Chem* 82:39–46. https://doi.org/10.1080/03610470.2024.2335828

Kirkpatrick KR, Shellhammer TH. 2018a. A cultivar-based screening of hops for dextrin degrading enzymatic potential. *J Am Soc Brew Chem* 76:247–256. https://doi.org/10.1080/03610470.2018.1546091

Kirkpatrick KR, Shellhammer TH. 2018b. Evidence of dextrin hydrolyzing enzymes in Cascade hops (*Humulus lupulus*). *J Agric Food Chem* 66:9121–9126. https://doi.org/10.1021/acs.jafc.8b03563

Kirkpatrick KR. 2018. Investigating hop enzymes. Master's thesis, Oregon State University, Corvallis, Oregon.

Klimczak K, Cioch-Skoneczny M, Duda-Chodak A. 2023. Effects of dry-hopping on beer chemistry and sensory properties - a review. *Molecules* 28:6648. https://doi.org/10.3390/molecules28186648

Krogerus K, Gibson BR. 2013. Diacetyl and its control during brewery fermentation. *J Inst Brew* 119:86-97. https://doi.org/10.1002/jib.84

Silva Ferreira C, Thibault de Chanvalon E, Bodart E, Collin S. 2018. Why humilones are key bitter constituents only after dry hopping: comparison with other Belgian styles. *J Am Soc Brew Chem* 76:236-246. https://doi.org/10.1080/03610470.2018.1503925

Teraoka R, Kanauchi M, Bamforth CW. 2021. Do starch degrading enzymes in hop samples originate in microorganisms? *Tech Q Master Brew Assoc Am* 58:705–710. https://doi.org/10.1094/TQ-58-3-0705-01

Vollmer DM, Shellhammer TH. 2016. Dry hopping on a small scale: considerations for achieving reproducibility. *Tech Q Master Brew Assoc Am* 53:140–144. http://dx.doi.org/10.1094/TQ-53-3-0814-01

Werrie PY, Deckers S, Fauconnier ML. 2022. Brief insight into the underestimated role of hop amylases on beer aroma profiles. *J Am Soc Brew Chem* 80:66–74. https://doi.org/10.1080/03610470.2021.1937453

Wietstock P, Michalek D, Treetzen T, Pinto MBC, Biendl M, Gibson B. 2025. Diastatic activity of German hop cultivars with respect to variety, crop year, and separated hop cone parts. *ACS Food Sci Technol* 5, 2408–2416. https://doi.org/10.1021/acsfoodscitech.5c00217

Willemart G, Tanriverdi Y, Collin S. 2025. Impact of contact time, temperature, and ethanol content on hop creep-related enzymatic activities in beer. *J Am Soc Brew Chem* 83:1-7. https://doi.org/10.1080/03610470.2024.2432146

Young J. 2021. Serial repitching method for New England IPAs with mid-fermentation dry hopping. *Tech Q Master Brew Assoc Am* 58:100–105. https://doi.org/10.1094/TQ-58-2-0430-01

Young J, Oakley WRM, Fox G. 2023. *Humulus lupulus* and microbes: exploring biotic causes for hop creep. *Food Microbiol* 113:104298. https://doi.org/10.1016/j.fm.2023.104298

Young J, Fox G. 2025. A fresh perspective on hop composition: the discovery of starch in hop cones (*Humulus lupulus*). *J Am Soc Brew Chem* 83:282-287. https://doi.org/10.1080/03610470.2025.2455336