



 HPA


**VIRTUAL
HARVEST
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Maximise fruity hop flavours in beer

Simon Whittock: Hi, I'm Simon Whittock, Manager of HPA's Agronomic Services and have been looking after our breeding program since 2007. I'm going to give you a presentation today about my thoughts around how hop breeders and brewers can work to maximise fruity flavours from hops in beer.

The slides that I've put together today represent some of my thinking around how compounds in hops translate to fruity flavours in beer. There's a model to the slides in that there's a lot of information on the slides that I won't necessarily be mentioning in the narrative, particularly the references to published papers. The references that are contained in the slides are generally in publicly available papers, so for those who are interested, please look them up, go find them, and understand what the authors are saying in there, otherwise I'll be running through the key points in each slide to get the narrative of the presentation across.

There are a number of compounds produced by hops that result in different flavour traits in beer. There are several classes of compounds that create fruity flavours. Some are transferred directly to beer, while others are non-flavour-active precursors in hops that are modified by bio-transformational processes in brewing that result in flavour active compounds in beer.

They key one that everyone knows about, the alpha acids, such as humulone, that are isomerised to provide bitterness, but there are also polyphenols that influence mouthfeel, the sesquiterpenes have been shown to produce spicy, resinous characters. You have monoterpenes such as myrcene, you have monoterpene alcohols such as linalool and geraniol, and the compounds that have become very well studied in the last few years, the sulphur-containing thiols.

I think it's interesting in the research that I've put in to understanding the biosynthesis of these compounds that the different groups of compounds that contribute different flavours to hops, those compounds originate in different biosynthetic pathways, and they can even be isolated to different sub-cellular localities within the cell of a plant. Some compounds are produced in the chloroplasts, while others are produced inside of the cell (in the cytoplasm).

What we need to zero in on for the fruity flavours in beer are primarily the monoterpene alcohols, such as linalool and geraniol, and the polyfunctional thiols. Linalool, geraniol, nerol, they're generally found as free compounds in hops or they're glycosidically bound precursors or geranyl esters that are then bio transformed by yeast.

The monoterpene alcohols have a specific role in citrus characters, such as lemon and lime. The polyfunctional thiols are defined by having three carbons between the S and the R group. When you have a short chain of carbons in the

backbone of the compound, three to four carbons tend to produce savoury characters. The hop-derived onion and garlic that everyone's familiar with, whereas if the carbon chain gets a little bit longer, say five to eight carbons, we tend to see floral, citrus fruit characters and potentially savoury, depending on the particular compound.

Hop-derived thiols have become compounds of interest to brewers in recent years with dry-hopping particularly taking the fore with flavour forward beers. Hops are a source of both free and bound thiol precursors. In dry-hopping, brewers are relying on yeast activity particularly to free thiols, fruit-dominant flavour thiols, from bound precursors, particularly relying on cystathionine beta-lyase activity in the yeast to release the fruit flavour causing thiols.

It's interesting when you look at the biology of thiol accumulation in plants, haven't seen a lot of work on this in hops, but the model for grape vines suggests that in normal, healthy growth, the amino acid accumulation from sulphite to cysteine is thrown to protein biosynthesis. When a plant is stressed, a different pathway kicks in cysteine's converted to glutathione and conjugates of glutathione and cysteine are what result in the precursors for the fruit flavour causing thiols once those precursors are exposed to yeast activity in beer.

From our own work and researching the literature, it appears that there's a fairly clear sequence of accumulation of flavour active metabolites as a hop crop matures. We first see maximal accumulation of prenyl flavonoids then beta acids then alpha acids, sesquiterpenes and monoterpenes in a time series as the hop crop matures. Originally I wrote this so that the free thiols were probably the last to accumulate, there was some evidence from some researchers in Japan that suggested that was so, but I've since seen some later research that suggests that the accumulation of thiols and their precursors may not be as time dependent as the banner at the bottom of this slide suggests.

At HPA what we actually measure in the run up to pre-harvest are cone weights, alpha acids, beta acids, essential oils, and the actual dry matter of the hop cone as we measure how much moisture is in the hop cones as they mature. We typically start it in mid-February and we'll continue monitoring fields right through to the end of harvest. When you plot those up on a time series you can see the metabolites, the alpha acids, beta acids, accumulate earlier than do the oil content. The key one for a hop grower, and it's indirectly important for brewers, is the cone weight. The cone weight peaks earlier than does the essential oil, and the peak of cone weight translates to the maximum yield that we can obtain from that variety in that season.

As a hop grower, we're juggling. We're making a judgement call as to what's the best bet between maximum metabolite accumulation and maximum yield to be able to supply brewers with the most flavour potential and of the highest quality.

The hop variety that everyone seems to want to know about these days, for me, is Eclipse. The maturity and metabolite accumulation of Eclipse. We see the maximum oil accumulation for Eclipse occur in late March, it's got an oil profile that's very similar to Galaxy in that it is dominated by monoterpenes, myrcene particularly. There are very very low levels of sesquiterpenes in there, there's no humulene, or very little humulene, and very little caryophyllene. Flavour active compounds from the literature that are known to produce the sweet mandarin flavour are linalool, pinene, limonene, they're all monoterpenes. We've got decadienal and octanal as well in the list. It's likely that compounds like that occur in hops from the variety Eclipse and produce the mandarin flavour in beer that we see.

Through the development phase of this variety, we've seen that sweet mandarin, sweet orange flavour in both kettle-hopped and dry-hopped beers, suggesting that bio transformation may not necessarily be essential to get that character from Eclipse hops, but it's undeniable that bio transformation may play a role in maximising the intensity of flavour observed in some dry-hopped beers using Eclipse.

Thanks for listening, stay with us for a live Q&A, and I'm looking forward to answering your questions.

Owen Johnston: G'day, thanks for tuning in and hearing a few thoughts on how to maximise hop flavour in beer. I'm Owen Johnston, Head of Sales and Marketing here at HPA, and joining me today is Dr Simon Whittock, and a very special guest, Tim Matthews.

Tim Matthews: Great to be here. Thanks, OJ.

OJ: Tim is a 13-year veteran with Oskar Blues but now he holds the lofty title of Vice President of Global Brewing at CANarchy, where his focus is on improving everything from product innovation, raw material sourcing, and improving connection between brewers and growing. Tim, again, welcome and thanks very much for joining us today.

TM: It's always a pleasure OJ, thanks for having me.

OJ: Simon is head of our Agronomic Services and leads up our breeding program. Well-qualified for the role before taking it, as he holds a PhD in Quantitative Genetics, originally in eucalypts?

Simon Whittock: Tree breeding.

OJ: Tree breeding, there you go. Here in Tasmania we don't just grow hops, we also grow a lot of trees.

Having led our program for 13 years, Simon is well-qualified to call himself an expert on hop breeding and hop biochemistry and the juicy topics we're going to talk about today. Thanks for making yourself available in the middle of harvest.

SW: Thanks, OJ.

OJ: if you're listening to this session live, please feel free to use the chat box and leave any questions in there. We'll do our best to get to those by the end of the session.

Today we're talking about hop compounds and how they behave in the brewing process. This is an emerging field of study, this is constantly evolving and it's obviously an area that we try and keep abreast of for our own purposes on the farm, but we also attempt to feed what we know to the brewers for the benefit of our customers and their beers.

Simon, you're pretty passionate about this topic, how do you go about keeping up with the state of the science?

SW: It's relatively simple, it's putting time into following the literature, paying membership with the ASBC, look at the MBAA journals, go to conferences. If you're really really keen and you really want to learn, get involved in a research project and work on some published research, you'll learn a heap during that process.

OJ: From our perspective, we still have research linkages out there with universities.

SW: We're not actively funded at the moment, but we still have manuscripts in preparation and things like that.

OJ: Great, so the last phase of our linkages with universities and research institutes is still coming to a conclusion.

SW: And we've got other projects in preparation as well. They're not funded yet.

OJ: Exciting. We'll be sure to bring those into our communications with brewers when Simon's ready.

SW: When we get them done.

OJ: The presentation we watched just now, it's basically a demonstration of what we understand going on in the hop plants, what we think we know about how we can maximise the flavour potential of our hops. Tell me how some of this influences our decision on farm.

SW: It feeds back at multiple levels. The first level, that I face, we do use some of these inferences to look at the plants in our breeding program and make decisions around which ones to select or bring forward. The primary tool we have here is GCMS data from the hop oil. It's imperfect but I think there are clues there based on the information that has been developed over the last ten years or so, you can use that as a guide. It doesn't get you the one, but a better chance of finding something that's interesting.

OJ: So it has better resolution than just compound categories, but it isn't the silver bullet?

SW: Yeah, back that in with very early-stage nano-scale trial brewing and I think you can make some very good decisions quite early in the program, so that's exciting.

The other one is obviously around quality, so if we know at what stage to pick the plant, or how to set the crop up to target the metabolite profile that we know produces the best outcomes in beer, then obviously that helps us to manage the estate and get the product to the brewers.

OJ: is that particularly important, does that impact across multiple sites and soil types?

SW: It impacts across multiple sites because what we're trying to do is produce similar outcome from multiple sites. The science to establish the kind (influence?) of soil type, for example, is extraordinarily difficult and I think there's other things we need to learn before we go down that path.

OJ: So we stay focused on the things we can control?

Tim, over to you, my friend. For the benefit of the audience, can you give us a little insight into CANarchy?

TM: Sure thing. It is definitely complex yet simple. We collectivise seven different breweries across the country in craft beer and there are times when we have been able to consolidate, and there are some times when we've been able to stay proliferated. In the world of hops that's a perfect example of the variety in the approach that we've taken. We've tried to be consolidated and simple, focused, when working with our vendors, but utilising the multitude of brewers and different minds and approaches and theories that we all have in terms of evaluating the technical space. Also, how we're interacting and gaining intimacy with different hop varieties.

OJ: How many breweries in the group currently?

TM: We have Three Weavers in California, Wasatch & Squatters in Utah, Oskar Blues in Colorado, Austin and Brevard, North Carolina, Deep Ellum in Dallas, Texas, Perrin in Grand Rapids, Michigan, and Cigar City in Tampa, Florida.

And then you have a whole bunch of different brewing minds within those, too, so plenty of personality. It's been fun.

OJ: But if you can harvest that diversity, what a powerful tool. We'll touch on that again down the track.

Let's take a step back to Simon's comment a minute ago, how our understanding of the plant biology influences our growing on the farm. If we can come through with a plan as Simon's describing it, it's then over to the brewer to incorporate this knowledge into practical application. We're all familiar with where hops are added, whether it's hot side, before flame out, flame out, or even more complex challenges in the dry-hop setting, whereby transformation starts to confuse the whole process.

Can you kick off for me with some comments around fermentation and dry-hopping as it relates to how you see maximising flavour.

TM: It has been the key point trying to look at the hops in a different way than we ever have before, challenging what we think we know about what leads to the final hop flavour in beer. We look at all the different bio transformations, so we're releasing glycosidically bound terpenes, or even the manipulation of terpenes from one to the other. We look at yeast stress, it's not all about the positives, it can be about the negatives. Sometimes we do stress yeast to create positives, but we have found at times that yeast stress can lead to a whole bunch of the negatives, too.

Understanding the dry-hop creep, interesting as we've dug into that, we've noticed that other compounds other than the oils in such are contributing to the dry-hop creep itself, that secondary fermentation. For example, we do see a pickup in sugars and density after we dry-hop.

I can only say density because it could have been other things too, but it was affecting the measurement of extract and a real extract in our beer. Nonetheless we found out that yeast stress has been, especially in our working with hops from the southern hemisphere and any other hops that have high amounts of sulphur content compounds, thiols especially, the yeast can definitely work with those thiols and manipulate them into something great, tropical and such, but we've had some scenarios where it has turned it into mercaptan-type compounds.

Especially when we over-nutryfy we found that we don't need as much nutrients in our beers that get dry-hopped, especially with the dry-hop loads that we have today, and also overpitching, we like to under pitch. We know that autolysis can lead to a lot of different off flavours in dry-hopped beers. We did a trial with Eclipse four or five years ago and it was going great, super citrusy, mandarin and all that, and then we let it on the yeast for this one- or two-day extra period that probably didn't need to happen and it just flipped around like that. But that experience led us to understanding the stress effect downstream, and now we utilise that knowledge in a whole bunch of different beers.

OJ: It's an interesting commentary, though, isn't it? Because of course if you flipped that around to specific yeast esters in certain beer styles, yeast stress does play an important role. You talk about negative outcomes, but you have to investigate those to find out, and that's the important part. You guys now know that over nutrification, or over or under pitching, or obviously poor yeast health in general might affect your consistency of your dry-hop outcomes.

Certainly, in the early part of my career, dry-hopping was effectively this black box process, because some of this investigation hadn't been done, so we were all wondering why our dry-hop outcomes were always different. It's really satisfying to hear your insights in the role of yeast health, as well as the obvious things like timing and pH control. But yeast health playing a big role in hop-derived flavour outcomes really insightful, thank you.

You touched there on a few things. How does hop trialling in your – I lost count, you must have got to seven or eight breweries there describing CANarchy – how does hop trialling with new varieties look inside the co-op? And how do you share the learnings in between the group?

TM: The interaction with any hop that we eventually trial starts at the ground level. We collectivise our getting boots on the ground. We travel to different farms, not one person, not two people can travel to all the different farms we'd like to visit, and especially, you can travel there, but how do you really engage it? So we divide and conquer amongst us. We have five people in the group that really focus on it and are extensively involved in the hop industry working with our brokers and also working with groups like the hop quality group in various capacities and such.

In those environments we come to have these discussions with growers and breeders and when it's in the field we learn about it there, and it's all part of this validation process. It starts in the field and then it works to the kiln and then the conditioning pile, and then in the cut downstream. That takes up to two to three years sometimes before in talking with the breeder and the different vendors what they need next.

At that point we look at, we have various levels and different brewing from three barrel on up to 15 barrel, that we can evaluate a hop. We'll look at the hop, look at the analytics, too, it gives us a good guide, but eventually we want to brew with it, and when we do brew with it, we make sure we have, and we communicate the entire brew process, we try to obtain all the controls, all the methodology we could possibly have, we communicate it back, and then sensory.

Eventually we want to see a repeatability, so just one box, one crop, that's usually not enough. That's something shared by most people involved in this process. The data is very key. We dig into the GCMS, we dig into the analytics, we look at fermentation effects, and then supply that back and hopefully, eventually, get downstream into something we can incorporate into a dry-hop bill.

OJ: I'd say you've touched on a very important point for us, that validation is a key word, especially with new hop varieties, but also consistency. From the farm perspective we talk about consistent agronomic expectations, consistent yields, consistent performance in beer, and this feedback loop, as you describe it, Tim, between year-on-year sensory, meshing that in with the season has gone. I think we're very mutually aligned between grower and brewer, in a mutually beneficial outcome at that point, because consistency is important for both of us.

SW: We've got to treat the plants consistently on a farm. Consistent growing programs, consistent harvest programs, processing, all of that helps.

[crosstalk]

OJ: Tim, are you happy to tell me, just off the top of your head, a hop that you think you and your group understand really well?

TM: We've come to know Centennial very well over time because we've evaluated it on a high level, on a very thorough, exhaustive level for so long. Interestingly enough, in some way we've fallen a little bit out of love with it, mainly because we almost know too much about it, in many ways.

Through our analytics and through various brewing trials, we came to understand the effects in terms of the field, the effects in the kiln, the processing and in the brewing. We identified the negatives and where they were really being maximised, and we also evaluated the positives and how to actually get those consistent, especially in terms of communicating exactly what we want and what we'd seen was working with our brokers and growers.

OJ: The advantage to being over in the States is you can have your five hop specialists in the field at harvest time and those feedback loops are much shorter. Tim, you've been on farm with us two, three times now, our feedback loops are a little bit longer, but I certainly know that we have always benefitted from the deep, technical understanding, and challenges that you've fed back to us on performance or a deep dive into why we make decisions that we make.

We've just got a question from the audience, Will, one of our local brewers here, he's just wondering whether across your different sites, hop trialling recipes are consistent between the breweries? Or if you have side-by-side nuances?

TM: Plenty of nuances. There's still some art in the process that we take to incorporate hops into everything. The art is still guided by the science at every single facility. Plus, the taste. We have to admit that we are making a product for consumers, but the individual's taste will most certainly express itself in the beer. We do have, I do look for the same data every single time. I say, "Please get this data back", and in the format that I ask for it back, but in terms of how they're actually coming to that decision of what hop blend they're going to come up with, what direction they're going to go as a profile, it's very much to the individual brewer.

Each facility, each brand, has multiple brewers and people, and we're trying to expand it. We want more people to be engaging the hops as much as we can. Peoples' time is a big resource, but it's most certain, it's even more artistic in some ways just as fast as it's getting more scientific.

Hope that answers that.

OJ: A bit each way, we'll call that. But it's fair and reasonable across those sites and with such diversity of engineering and equipment, plus good thinkers in the business, you've got to harness that sort of diversity.

SW: I know every brewery is set up differently, so there's different demands on the hop in the beer from that brewery, so I think the consistency is in the experimental approach in that you're either setting up an experiment to prove or to amplify the hop to show its good side, or you're setting up an experiment to break it in a particular system.

Consistency of data format is really, really important, so if you've got that consistency of concept, consistency of reporting, you have variability in the different trial systems and still get really meaningful information.

OJ: you still have enough context for it to be meaningful.

Tim, just touch on what your key analytical equipment is in driving this important data generation.

TM: The batch-to-batch analytics that we do use are, we look at extract with a densitometer, we use an alkaliser for the alcohol, we use photometric analysis for basic fermentation, VDKs and acetaldehyde. Acetaldehyde is also a key indicator in yeast stress for us, and we use that as a way, and it does not jive with hop flavour, I can tell you that.

Ultimately the GCMS with some solid-phase micro extraction, we've been getting to know that machine over the last couple years. We use it to get fingerprints of hops. We don't have a target amount of anything, but the entire spectrum of what that hop delivers on a chromatograph is we overlay it year to year to year, and we start getting an idea of what varies, and also how certain hops, what they have and what others lack.

We've been formulating recipes by filling in the blanks.

OJ: Simon, does that resonate with you? Overlaying, year on year, whether it's GCMS SPME technology, or potentially the 2DGC with the overlay and the differences. Does that resonate with you?

SW: Absolutely. It definitely does, it's important for us. We had that conversation around consistency, so we can use these fingerprints to look at the consistency between sites or between seasons. The other element that I think is going to come, these metabolite data sets are relatively new, it's not that long that we've been dealing with these really big, really complex data sets, and that type of data and some particular characteristics. There is going to be a lot of power when someone figures out how to put these things together and visualise it properly.

It sounds like Tim's doing a grand job overlaying chromatograms year on year, that's a lot of work. It's not necessarily easy to interpret, but if somebody can come up with a way to simplify it. A bit of code, some smart stats to really show you what's changing and break that down.

OJ: There might still be some sort of gear stick in the middle. When we see this difference year on year, we know the Centennial profile is going more toward the floral than the citrus, for example. There might still be some use of your brain required. At least you'll have the lead indicators from a data-driven perspective, to be able to maybe forecast how a hop's going to perform.

Tim, you've been in the game now for a while, has your approach to managing hops and seeking hop impact in beer changed over your journey?

TM: It was only five or six years ago that we started formulating hop bills with up to five or six different varieties. That was borne out of trying to create a sustainable supply chain because we didn't want to be linked to just one variety. Say that variety had a down year, we're linked to that down aspect, so we created these supportive groups of hops in order to sustain it, but now it's all about innovation.

We are constantly being impressed as brewers to come up with new beers. Brands don't last nearly as long as they did, the ability to establish a brand, it's almost gone in some ways. There are some established brands that are persevering, and that is the perfect word: persevering. Now we are taking a hop arsenal approach, trying to have as diverse a quiver as possible. As we've gotten into different hops, everybody knows in the last ten years especially, and it's been 30 years in the making, but in the last ten years especially, the diversification of what a hop can bring to the table through the accelerated hop breeding, still methodical but Simon can probably tell you, the pressure on hop breeding is more than ever before, and what has emerged out of that is incredible.

To fully take advantage of that on our end, we're trying to look at, if we have 40 different varieties – that's a lot, but it's actually pretty close for seven different breweries – out of this we can always create a unique IPA or a unique pale ale or a unique pilsner. It does mean that when we want to focus on one variety, it's going to take some manipulation of our positions with our brokers and vendors, but there's always a way. If we're able to have this palette of hop flavour in order to construct beer flavour.

OJ: You've basically got, I feel like I'm picking up two things there, the hop arsenal allows you to innovate and, not simplify, but at least you know the supply chain and innovation pipeline are matched. Like you say, you can take whatever marketing is feeding in and whatever creative license the brewers have got, and you can use those 40-plus varieties to come up with something unique.

I'm also picking up that, with a hop arsenal approach, for those brands that are persevering, perhaps you have some recipe flex in them so that, year-on-year, can still adjust, so if you've overlayed your GCSM and you're saying your Centennial's up, maybe there's, in this arsenal approach you've got that flexibility to shift the hop grist and make sure that that complements the best outcome for maximising hop flavour in those beers.

Have I gone too far with that second theme there?

TM: No, that is very much an approach we'd use. For example, Dale's Pale Ale has swapped around hops three times in the last six years. We still focus on a target profile, but we're not married to a variety, we're married to a profile. I think you can obtain that profile through some kind of rearrangement occasionally. As long as you understand the hop, and as long as you engage the hop.

OJ: I think that's a fantastic approach, and certainly in my own personal experience I've had beers that are dead in the water because I've been too stubborn to flex the hop bill in them. When the European crops in '07 and '08 were doing it tough, my beer was doing it tough because I was too pig-headed to flex. Again, I appreciate those comments.

Guys, we're going to wrap up. Tim, thank you so much for your contribution. It's been a really enlightening chat, I've certainly learned a lot. Simon, thanks for making yourself available at a very busy time of the year. Tim, we look forward to welcoming you back on the HPA farms as soon as we can make that happen.

TM: I can't wait to get back down. It's one of the many trips I can't wait to get out of Colorado for. Until then.

OJ: Thank you.

SW: Thanks, Tim.

OJ: A huge thank you to everyone who was part of this session. If you missed some of the action because you couldn't understand our Aussie accent, a recording will be uploaded to hops.com.au/virtual-harvest. For further information, please email info@hops.com.au, and we hope to welcome you all on farm again soon.