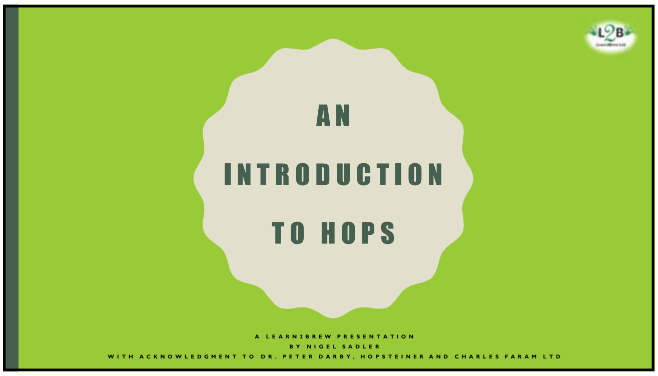
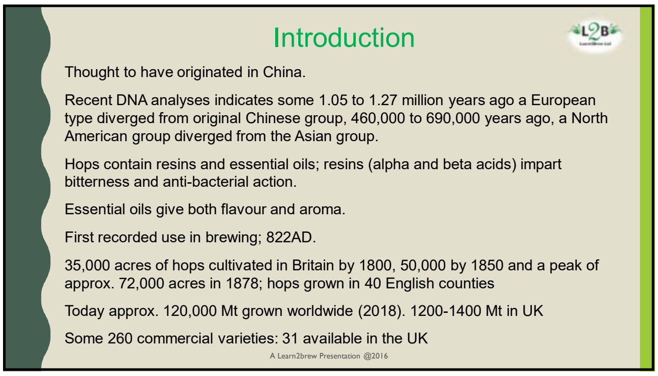


AN INTRODUCTION TO HOPS

A LEARN2BREW PRESENTATION
BY NIGEL SADLER
WITH ACKNOWLEDGMENT TO DR. PETER DARBY, HOPSTEINER AND CHARLES FARAM LTD



Introduction

Thought to have originated in China.

Recent DNA analyses indicates some 1.05 to 1.27 million years ago a European type diverged from original Chinese group, 460,000 to 690,000 years ago, a North American group diverged from the Asian group.

Hops contain resins and essential oils; resins (alpha and beta acids) impart bitterness and anti-bacterial action.

Essential oils give both flavour and aroma.

First recorded use in brewing; 822AD.

35,000 acres of hops cultivated in Britain by 1800, 50,000 by 1850 and a peak of approx. 72,000 acres in 1878; hops grown in 40 English counties

Today approx. 120,000 Mt grown worldwide (2018). 1200-1400 Mt in UK

Some 260 commercial varieties: 31 available in the UK

Been Around a Long Time!

Fig. 1.7. Macrofossils of *Humulus* from the Eocene of Colorado (37.2 - 33.9 mya; MacGinitie 1953 and 1969, Manchester 2001).

Brief History of Cultivation

- Commercial hop growing in Europe from AD800? In Britain from at least 1524.
- First used by Flemish brewers who came to England c. mid-1300s AD (?)
- Evidence of earlier hop trading: Graveney boat wreck c.950 AD?
- By 1670s different types of hops with differing attributes were noted.
- Early English varieties; Farnham Pale and Canterbury Whitebine.
- By mid-1700s brewers knew quantities of hops required to produce a certain level of bitterness varied between different varieties. They also noted the differences in the keeping qualities of beers brewed with various hop varieties.
- 1900 over 20 varieties known in England and at least 60 recorded in mainland Europe.
- The Wye programme, started by Dr Salmon in 1906, laid the foundations for all hop breeding during the twentieth century.

A Learn2brew Presentation @2018

Brief History of Cultivation

- Few varieties grown in 1900 were >4% alpha-acid content.
- Wye Target (1972) first variety to exceed 10% alpha-acid consistently in commercial production.
- At end of 20th century varieties available producing more than 16-18%.
- World's first dwarf varieties; First Gold, Herald and Pioneer registered in 1996.
- The world's first aphid-resistant variety, Boadicea, variety rights granted 2008.
- Short day length varieties released in 1992; the first varieties able to be grown without additional lighting (South Africa).
- National Scientific Hop Collection, China Farm near Canterbury – 800 varieties (450 female and 350 male).
- The future? Flavour, aroma, uniqueness. Molecular breeding.

A Learn2brew Presentation @2018

Early Varieties Bred by Growers

1730(?): Farnham Pale
1737: Mathon (aka Canterbury Whitebine)
1790: Old Golding (from Canterbury Whitebine)
1805: Colegate
1838: East Kent Golding (aka Canterbury Golding)
1865: Bramling
1875: Fuggle (Contains traces of Saaz and Hallertauer)
1881: Cobbs
1887: Early Bird (Amos)
1889: Eastwell Golding

A Learn2brew Presentation @2018

Traditional Hop Breeding

At least five years to identify a promising new hop variety. Potentially a further six years to take it into commercial cropping. Typical breeding cycle via Dr. P. Darby is:

Year 1: Create variety crosses
Year 2: Raising seeds
Year 3: First assessment of individual seedlings (resin analyses and aroma assessment)
Year 4: Mature hop harvesting; yield, plant health and cone shape
Year 5: Selection of potential varieties and propagation of material for commercialisation
Year 6: Planting of small trial plots
Year 7: Assessment of commercial attributes: suitability for machine harvesting, yield, oil and resin analysis, and disease resistance
Year 8: Assessment of mature plants for habit and pilot brewing trials
Year 9: Propagation of materials for planting on farms
Year 10: Planting on farms
Year 11: Commercial crop

Research & Breeding

1906: Prof E S Salmon at Wye College planted out new hop seedlings to create new Alpha / Bittering varieties that “possess marketable value”. Bred: 1934: Brewers Gold, 1938: Bullion, 1940: Nonsuch, 1944: Northern Brewer,1946: Pride of Kent, 1948: Early Choice, 1949: Keyworths Early / Midseason, 1951: Bramling Cross

1949: Dr W G Keyworth, wilt resistance. Bred: 1960: Defender, 1960: Density, 1960: Janus

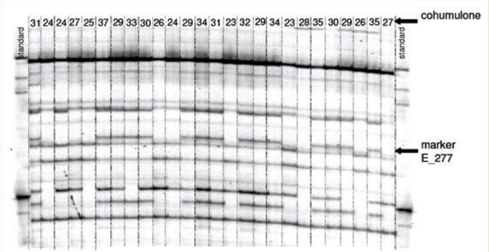
1953: Dr R A Neve, disease & wilt resistance. Bred: 1967: Progress, 1971: Northdown, 1972: Challenger, 1972: Target, 1983: Yeoman

1981: Dr Peter Darby, pioneer of “dwarfed” varieties: Bred: 1996: Admiral, 1996: First Gold, 1996: Phoenix, 1996: Pioneer, 2001: Pilgrim, 2001: Pilot, 2004: Boadicea, 2006: Sovereign.

Modern Hop Breeding

- Uses genetic markers to establish certain traits and characteristics
- More science based. Not GM!
- 1999: 250 markers were known; not much use to breeders
- 2014: 17,200 markers known; “molecular breeding” has arrived.
- Much reduced time for selecting potential crosses and waiting results.
- Test the parents not the offspring!
- Genetic map being developed to help locate traits on chromosomes.

Modern Hop Breeding



Marker for high cohumulone content

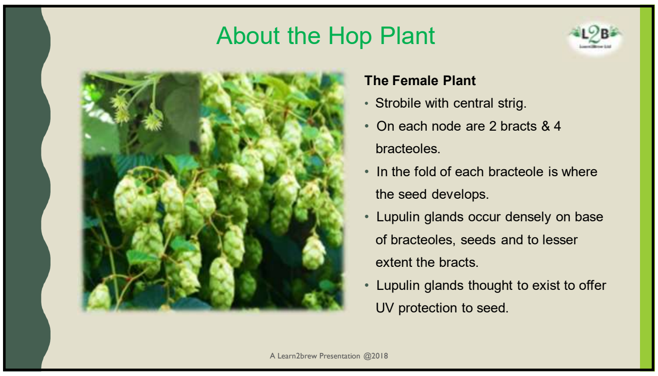
About the Hop Plant

- Botanical name: Humulus lupulus.
- Other varieties: H. Japonicus and H. Yunnanensis: No interest to brewers.
- Related to the hemp (cannabis) family.
- Hardy climbing perennial herbaceous plant.
- Grow annually from the same rootstock to produce large bines between 4 and 7 meters long (depending on variety and growing systems), which are usually supported on overhead wires in the hop gardens or hop yards.
- Productive life ranges from 8 to 15 years though the plant may well live for 40 years.
- Once the hop cones on the bines are ripe they are harvested usually at the end of August or in September in the Northern Hemisphere, and February or March in the Southern Hemisphere.

About the Hop Plant

The Male Plant

- Flowers consist of 5 sepals & 5 anthers.
- Only a few lupulin glands.
- Flowers drop off - no brewing value.
- Normally one male plant to 3-400 female plants.
- Outside of England male plants often removed by growers.
- Seed thought to contribute lipids and astringency to wort.



About the Hop Plant

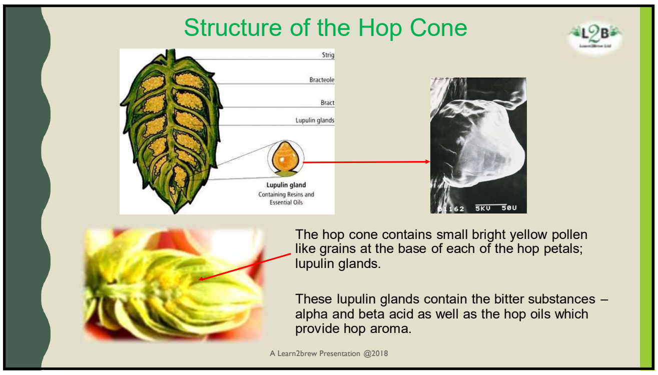
The Female Plant

- Strobile with central strig.
- On each node are 2 bracts & 4 bracteoles.
- In the fold of each bracteole is where the seed develops.
- Lupulin glands occur densely on base of bracteoles, seeds and to lesser extent the bracts.
- Lupulin glands thought to exist to offer UV protection to seed.

A Learn2brew Presentation @2018

All Shapes and Sizes

A Learn2brew Presentation @2018



Structure of the Hop Cone

The hop cone contains small bright yellow pollen like grains at the base of each of the hop petals; lupulin glands.

These lupulin glands contain the bitter substances – alpha and beta acid as well as the hop oils which provide hop aroma.

A Learn2brew Presentation @2018

Variation

Like all naturally grown ingredients there will be seasonal variation; “vintages”.

Terroir (see below) plays an important role in hop character.

1. As with an ear of barley not all hop cones are the same; variation in lupulin content which can be further exacerbated during processing.
2. Position on the hop bine (see below)
3. Terroir; location, angle of slope, soil, sunlight, rainfall etc.
4. Seasonal changes; temperature, frost, rain, daylength etc.

Position on the bine	Alpha Acid (%)	Total Oil (mg/100g)
Head	14.2	2.92
Top	13.8	2.77
Middle	12.1	2.43
Bottom	10.9	1.39

Hop Growing Regions of the World

Hops require, in general, a minimum 13 hours daylight to grow and flower i.e. produce hop cones.

2017 Hop Crop Key Data

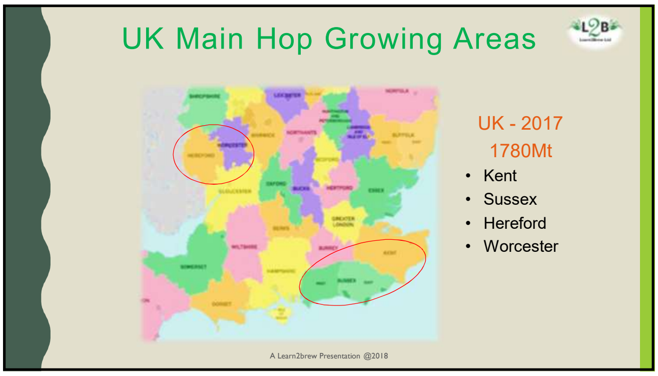
Source: Barth Haas Hop Report 2018

USA: Main Hop Growing Areas

USA - 2017
48,190 Mt

Washington (71%)
(Yakima Valley)
Oregon (15%)
(Willamette Valley)
Idaho (11%)

A Learn2brew Presentation @2018

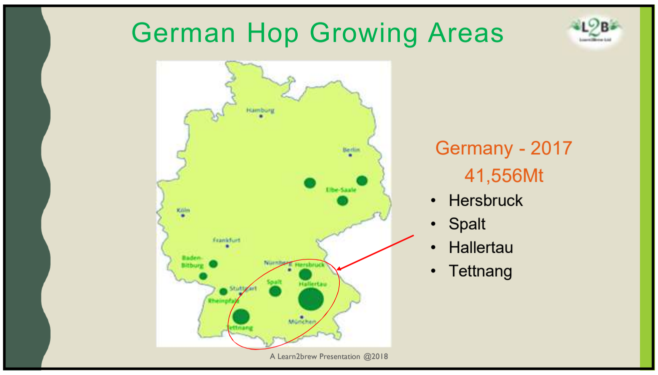


UK Main Hop Growing Areas

UK - 2017
1780Mt

- Kent
- Sussex
- Hereford
- Worcester

A Learn2brew Presentation @2018



German Hop Growing Areas

Germany - 2017
41,556Mt

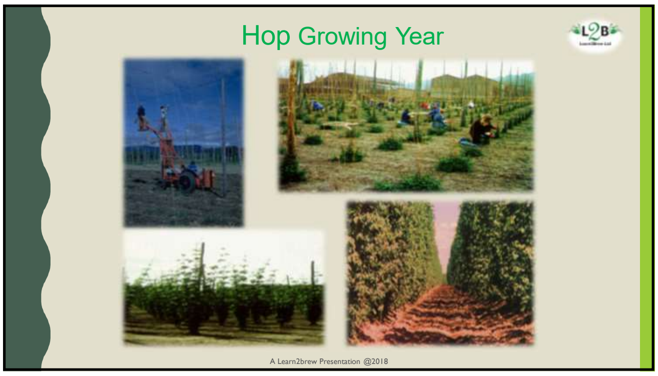
- Hersbruck
- Spalt
- Hallertau
- Tettnang

A Learn2brew Presentation @2018

Hop Growing Year

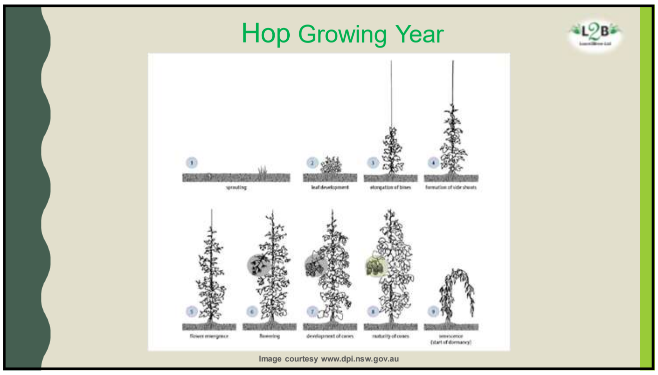
February/March:	Cleaning & clearing; start stringing.
April/May:	Hops start to grow; workers remove excess shoots and train bines around strings.
June:	Bines reach top of strings; hop flowers begin to develop.
July:	Hop cones start to develop.
August:	Cones mature and ripen.
September:	Harvest time.
December/January:	Looking at new varieties to plant?

A Learn2brew Presentation @2018



Hop Growing Year

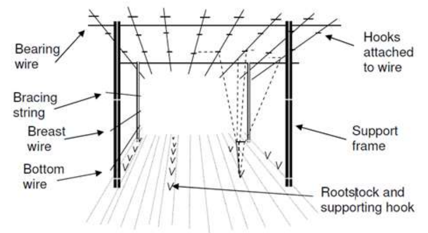
A Learn2brew Presentation @2018



Hop Growing Year

Image courtesy www.dpi.nsw.gov.au

Stringing



Supporting frame for hop growing; trellis

Harvesting

Hops should be harvested 10 days after ripening; overripe cones shatter.

Historically growing was extremely labour intensive and still is to some degree.

With the technological revolution, harvesting has become more automated.

Harvesting steps are as follows:

- Bines are cut down and transported to a picking machine, which strips the cones from the bine.
- Cones are separated, the debris, leaves and strig, screened and removed.
- The picked hops are dried from ~80% to 10% moisture in kilns, similar to those used for malting. Drying prevents deterioration.
- After drying the hops require a short period of conditioning to achieve an even distribution of moisture before being compressed and packed into bales or in England “hop pockets” to reduce storage requirements and costs.
- The whole hops can then be used as is, or after processing as pellets, powders, extracts.

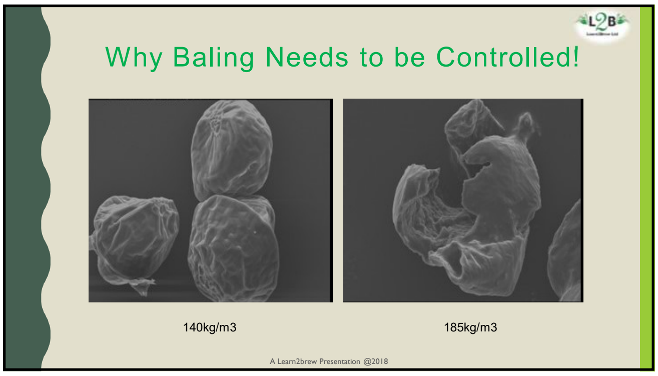
Hop Picking in England

The baled hops are marked and transferred to a cold store to reduce any loss of bittering compounds.

Each batch of hops is coded with the variety, farm and % alpha acid.

The hops may be used as cones or go on for pelletising or extracting

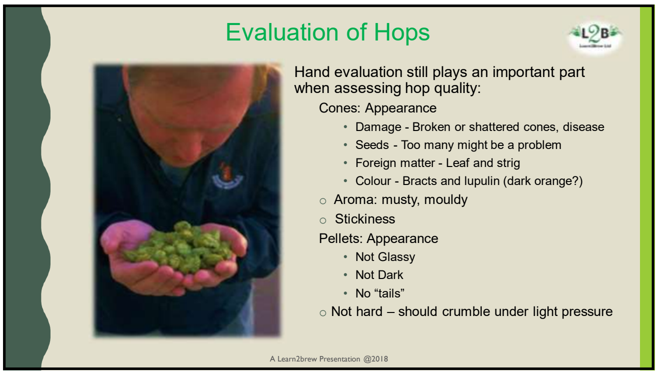
Charles Faram - Video



Why Baling Needs to be Controlled!

140kg/m3

185kg/m3



Evaluation of Hops

Hand evaluation still plays an important part when assessing hop quality:

Cones: Appearance
- Damage - Broken or shattered cones, disease
- Seeds - Too many might be a problem
- Foreign matter - Leaf and strig
- Colour - Bracts and lupulin (dark orange?)

○ Aroma: musty, mouldy

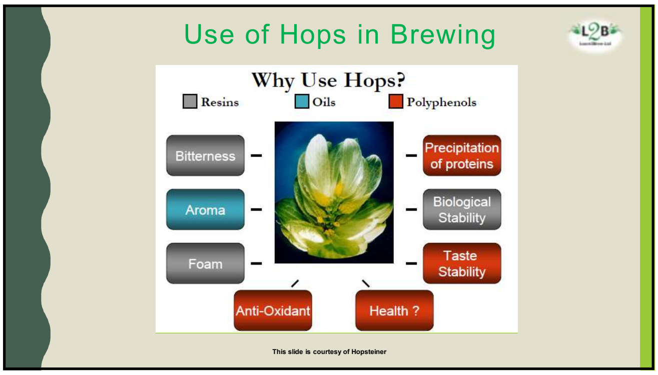
○ Stickiness

Pellets: Appearance
- Not Glassy
- Not Dark
- No "tails"

○ Not hard – should crumble under light pressure

BEER BREAK!

THE USE OF HOPS IN BREWING



Use of Hops in Brewing

Why Use Hops?

- ▨ Resins
- 🟦 Oils
- 🟥 Polyphenols

This slide is courtesy of Hopsteiner

Hop Additions

Added during the production of beer in, usually, 2 or 3 stages.

Hops contain 2 types of resin: hard and soft. The soft resins account for 97-98% of the total.

Soft resins further divided into alpha, beta and gamma acids.

Bittering effect comes principally from the alpha acid content with small contribution from beta acids. (Gamma acid plays no role in brewing as far as known).

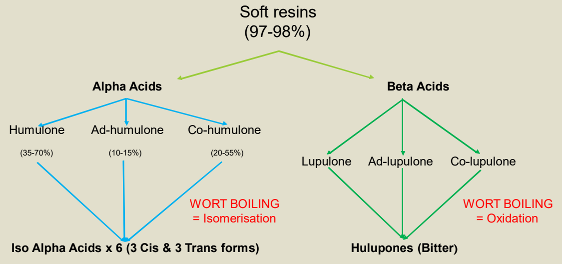
Some 300 essential oils have been detected by HPLC; give aroma.

Other compounds also contribute to aroma.

Typical Dried Hop Composition (%)

Water	<10
Resin	5-25
Essential Oils	0.5-3
Cellulose	38-40
Polyphenols	3 - 8
Pectins	2
Protein	15
Lipids & waxes	3

Hop Resins



Soft resins
(97-98%)

Alpha Acids

Humulone (35-70%)

Ad-humulone (10-15%)

Co-humulone (20-55%)

WORT BOILING = Isomerisation

Iso Alpha Acids x 6 (3 Cis & 3 Trans forms)

Beta Acids

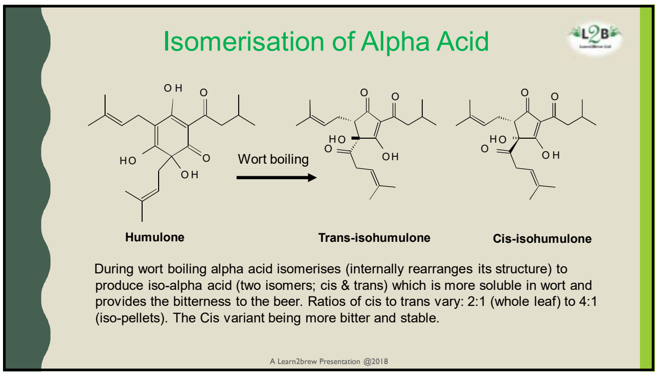
Lupulone

Ad-lupulone

Co-lupulone

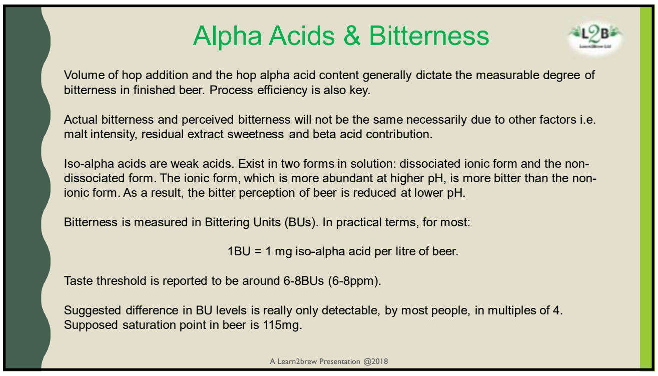
WORT BOILING = Oxidation

Hulupones (Bitter)



Isomerisation of Alpha Acid

During wort boiling alpha acid isomerises (internally rearranges its structure) to produce iso-alpha acid (two isomers; cis & trans) which is more soluble in wort and provides the bitterness to the beer. Ratios of cis to trans vary: 2:1 (whole leaf) to 4:1 (iso-pellets). The Cis variant being more bitter and stable.



Alpha Acids & Bitterness

Volume of hop addition and the hop alpha acid content generally dictate the measurable degree of bitterness in finished beer. Process efficiency is also key.

Actual bitterness and perceived bitterness will not be the same necessarily due to other factors i.e. malt intensity, residual extract sweetness and beta acid contribution.

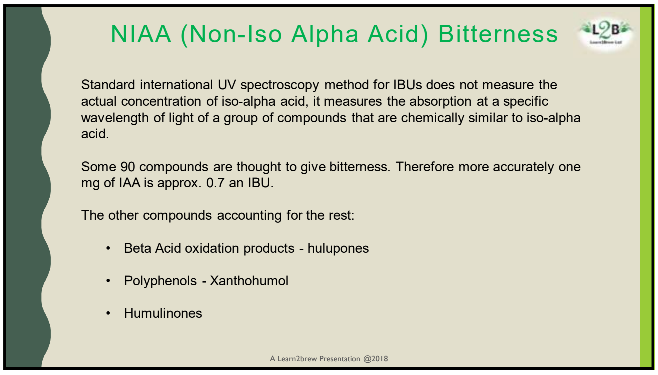
Iso-alpha acids are weak acids. Exist in two forms in solution: dissociated ionic form and the non-dissociated form. The ionic form, which is more abundant at higher pH, is more bitter than the non-ionic form. As a result, the bitter perception of beer is reduced at lower pH.

Bitterness is measured in Bittering Units (BUs). In practical terms, for most:

1BU = 1 mg iso-alpha acid per litre of beer.

Taste threshold is reported to be around 6-8BUs (6-8ppm).

Suggested difference in BU levels is really only detectable, by most people, in multiples of 4. Supposed saturation point in beer is 115mg.



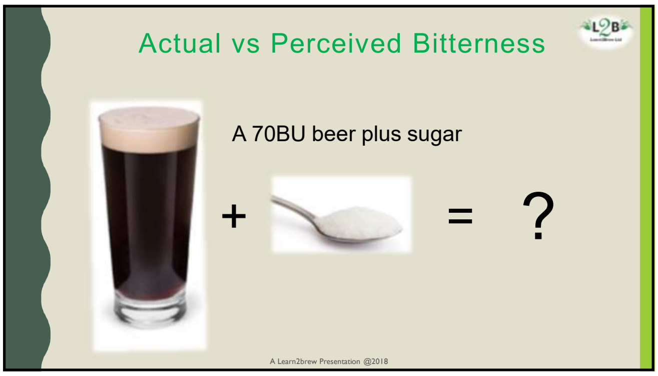
NIAA (Non-Iso Alpha Acid) Bitterness

Standard international UV spectroscopy method for IBUs does not measure the actual concentration of iso-alpha acid, it measures the absorption at a specific wavelength of light of a group of compounds that are chemically similar to iso-alpha acid.

Some 90 compounds are thought to give bitterness. Therefore more accurately one mg of IAA is approx. 0.7 an IBU.

The other compounds accounting for the rest:

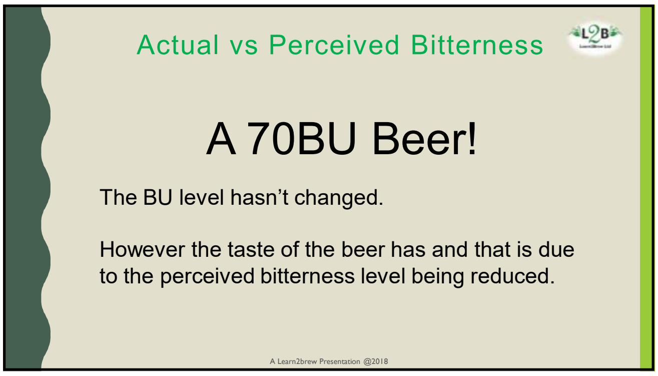
- Beta Acid oxidation products - hulupones
- Polyphenols - Xanthohumol
- Humulinones



Actual vs Perceived Bitterness

A 70BU beer plus sugar

+ = ?

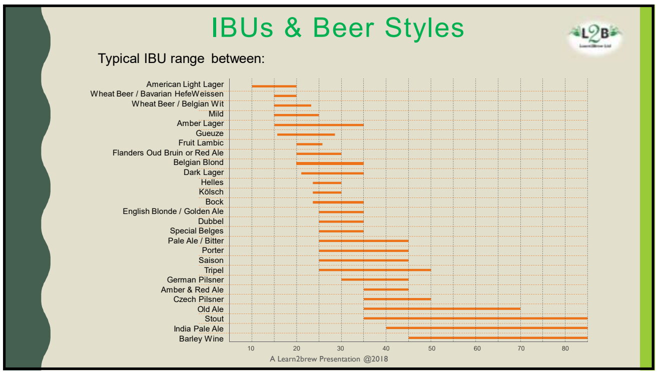


Actual vs Perceived Bitterness

A 70BU Beer!

The BU level hasn't changed.

However the taste of the beer has and that is due to the perceived bitterness level being reduced.



IBUs & Beer Styles

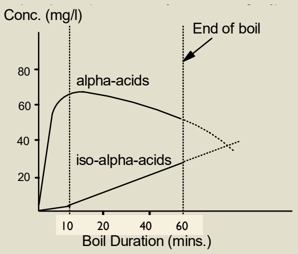
Typical IBU range between:

Hop Utilisation

$$\% \text{ Utilisation} = \frac{\text{Amount of iso-alpha-acid in beer}}{\text{Amount of alpha-acid added}} \times 100$$

Hop utilisation compares the bitterness in final beer against amount of bitterness added to the copper

Hop Utilisation During Wort Boiling



Wort boiling is quite an inefficient method of isomerisation.

Only around 50 – 60% of all the alpha is converted in the boiled wort: 50% within 30 minutes.

Approx. 25 to 35% of the alpha finishes up in the beer.

Factors Affecting Utilisation Rate

- Maximum solubility of iso-alpha acids is about 115 ppm (Alpha acids are not very soluble in wort; 3-5ppm)
- Solubility increases with time, temperature and pH
- Wort pH (Higher pH = more utilization; greatest at pH9): Coarser?
- Presence of Mg and Ca
- Gravity (boiling point & increased trub, more = less)
- Hopping rate (more hops = worse utilisation)
- Yeast adsorption & foam loss in fermentation

Effect of Wort Gravity on HUR

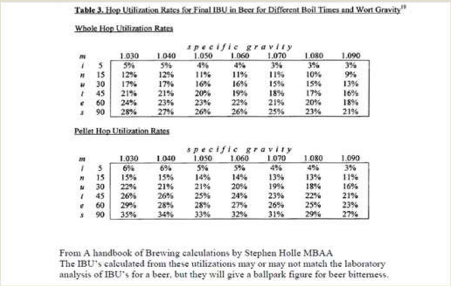


Table 3. Hop Utilization Rates for Final IBU in Beer for Different Boil Times and Wort Gravity[19]

Whole Hop Utilization Rates

		specific gravity						
m		1.030	1.040	1.050	1.060	1.070	1.080	1.090
i	5	5%	5%	4%	4%	3%	3%	3%
n	15	12%	12%	11%	11%	11%	10%	9%
u	30	17%	17%	16%	16%	15%	15%	13%
t	45	21%	21%	20%	19%	18%	17%	16%
e	60	24%	23%	23%	22%	21%	20%	18%
s	90	28%	27%	26%	26%	25%	23%	21%

Pellet Hop Utilization Rates

		specific gravity						
m		1.030	1.040	1.050	1.060	1.070	1.080	1.090
i	5	6%	6%	5%	5%	4%	4%	3%
n	15	15%	15%	14%	14%	13%	13%	11%
u	30	22%	21%	21%	20%	19%	18%	16%
t	45	26%	26%	25%	24%	23%	22%	21%
e	60	29%	28%	28%	27%	26%	25%	23%
s	90	35%	34%	33%	32%	31%	29%	27%

From A handbook of Brewing calculations by Stephen Holle MBAA
The IBU's calculated from these utilizations may or may not match the laboratory analysis of IBU's for a beer, but they will give a ballpark figure for beer bitterness.

BU Addition Calculation

Example:
5kg of hops at 8% alpha acid =

5000g x 0.08 = 400g of alpha acid

400g x 1000 = 400,000mg alpha acid

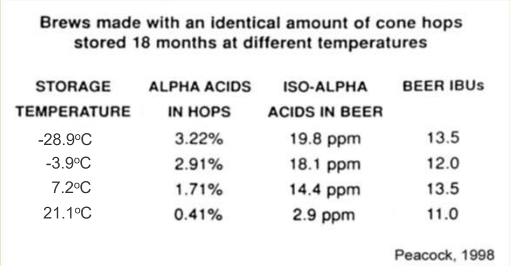
Say 30% of this converts in the boil to iso-alpha acid and goes through to finished beer, we then end up with:

400,000mg x 30% = 120,000mg iso-alpha acid

If we have brewed 5000 litres of beer, then IBU level =

120,000mg iso-AA / 5000 litres = 24mg iso-AA/litre or 24 BUs

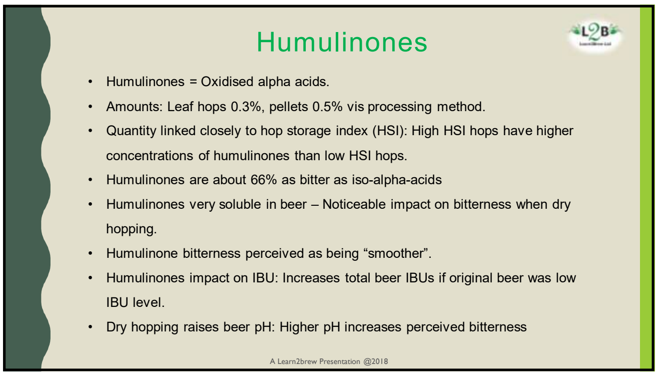
Can You Still Brew With Old Hops?



Brews made with an identical amount of cone hops stored 18 months at different temperatures

STORAGE TEMPERATURE	ALPHA ACIDS IN HOPS	ISO-ALPHA ACIDS IN BEER	BEER IBUs
-28.9°C	3.22%	19.8 ppm	13.5
-3.9°C	2.91%	18.1 ppm	12.0
7.2°C	1.71%	14.4 ppm	13.5
21.1°C	0.41%	2.9 ppm	11.0

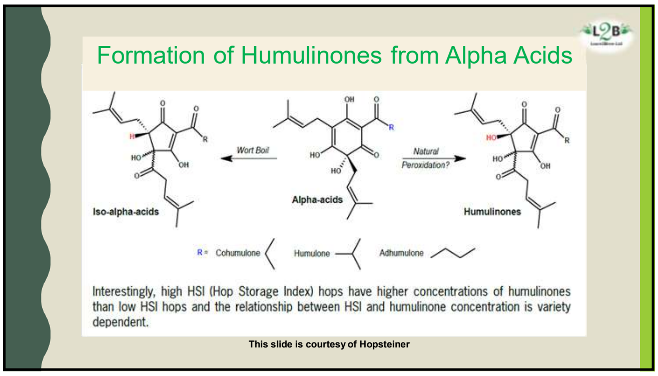
Peacock, 1998



Humulinones

- Humulinones = Oxidised alpha acids.
- Amounts: Leaf hops 0.3%, pellets 0.5% vis processing method.
- Quantity linked closely to hop storage index (HSI): High HSI hops have higher concentrations of humulinones than low HSI hops.
- Humulinones are about 66% as bitter as iso-alpha-acids
- Humulinones very soluble in beer – Noticeable impact on bitterness when dry hopping.
- Humulinone bitterness perceived as being “smoother”.
- Humulinones impact on IBU: Increases total beer IBUs if original beer was low IBU level.
- Dry hopping raises beer pH: Higher pH increases perceived bitterness

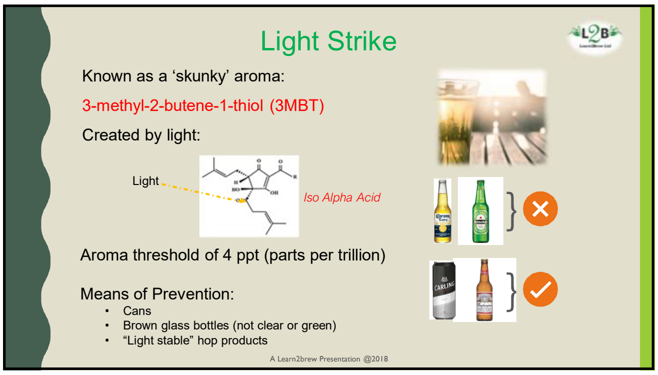
A Learn2brew Presentation @2018



Formation of Humulinones from Alpha Acids

Interestingly, high HSI (Hop Storage Index) hops have higher concentrations of humulinones than low HSI hops and the relationship between HSI and humulinone concentration is variety dependent.

This slide is courtesy of Hopsteiner



Light Strike

Known as a ‘skunky’ aroma:

3-methyl-2-butene-1-thiol (3MBT)

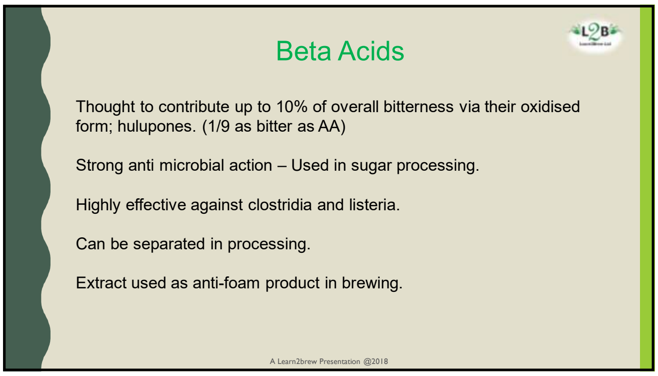
Created by light:

Aroma threshold of 4 ppt (parts per trillion)

Means of Prevention:

- Cans
- Brown glass bottles (not clear or green)
- “Light stable” hop products

A Learn2brew Presentation @2018



Beta Acids

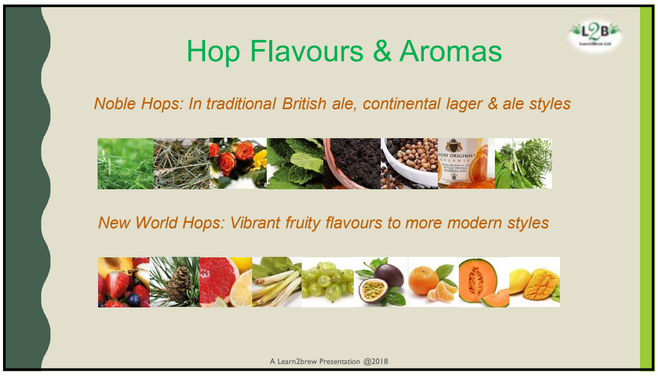
Thought to contribute up to 10% of overall bitterness via their oxidised form; hulupones. (1/9 as bitter as AA)

Strong anti microbial action – Used in sugar processing.

Highly effective against clostridia and listeria.

Can be separated in processing.

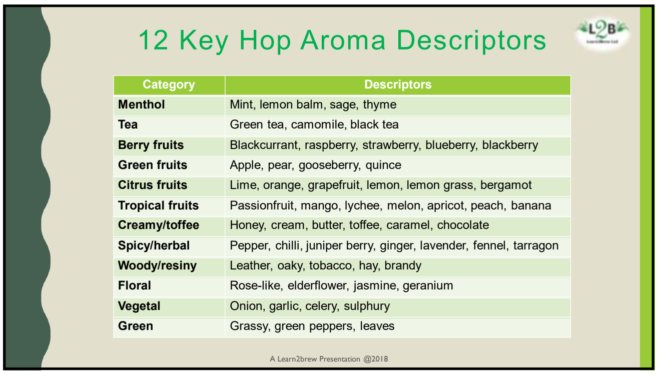
Extract used as anti-foam product in brewing.



Hop Flavours & Aromas

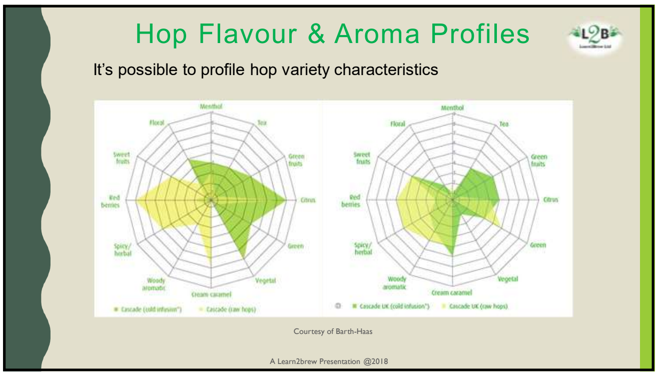
Noble Hops: In traditional British ale, continental lager & ale styles

New World Hops: Vibrant fruity flavours to more modern styles



12 Key Hop Aroma Descriptors

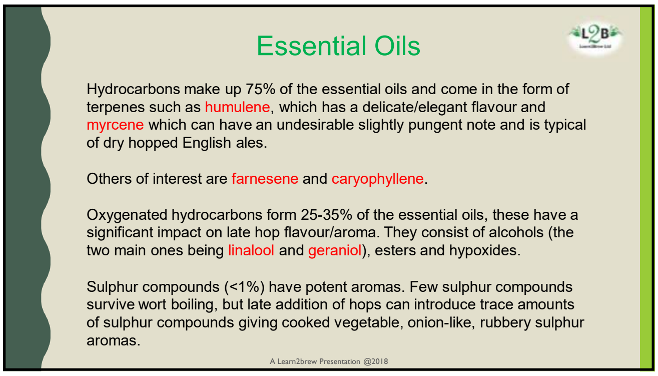
Category	Descriptors
Menthol	Mint, lemon balm, sage, thyme
Tea	Green tea, camomile, black tea
Berry fruits	Blackcurrant, raspberry, strawberry, blueberry, blackberry
Green fruits	Apple, pear, gooseberry, quince
Citrus fruits	Lime, orange, grapefruit, lemon, lemon grass, bergamot
Tropical fruits	Passionfruit, mango, lychee, melon, apricot, peach, banana
Creamy/toffee	Honey, cream, butter, toffee, caramel, chocolate
Spicy/herbal	Pepper, chilli, juniper berry, ginger, lavender, fennel, tarragon
Woody/resiny	Leather, oaky, tobacco, hay, brandy
Floral	Rose-like, elderflower, jasmine, geranium
Vegetal	Onion, garlic, celery, sulphury
Green	Grassy, green peppers, leaves



Hop Flavour & Aroma Profiles

It's possible to profile hop variety characteristics

Courtesy of Barth-Haas



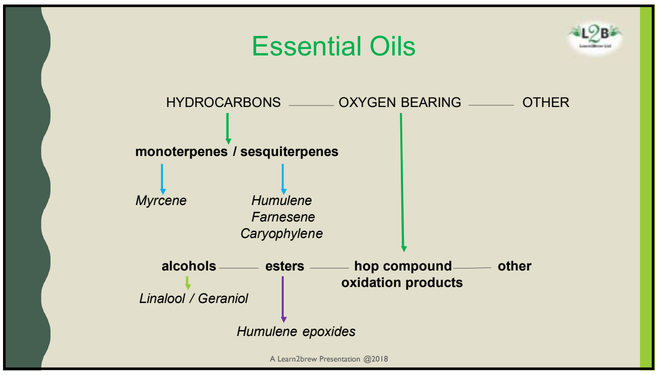
Essential Oils

Hydrocarbons make up 75% of the essential oils and come in the form of terpenes such as humulene, which has a delicate/elegant flavour and myrcene which can have an undesirable slightly pungent note and is typical of dry hopped English ales.

Others of interest are farnesene and caryophyllene.

Oxygenated hydrocarbons form 25-35% of the essential oils, these have a significant impact on late hop flavour/aroma. They consist of alcohols (the two main ones being linalool and geraniol), esters and hypoxides.

Sulphur compounds (<1%) have potent aromas. Few sulphur compounds survive wort boiling, but late addition of hops can introduce trace amounts of sulphur compounds giving cooked vegetable, onion-like, rubbery sulphur aromas.



Essential Oils

HYDROCARBONS — OXYGEN BEARING — OTHER

monoterpenes / sesquiterpenes

Myrcene

Humulene
Farnesene
Caryophylene

alcohols — **esters** — **hop compound oxidation products** — **other**

Linalool / Geraniol

Humulene epoxides

Essential Oils - Hydrocarbons

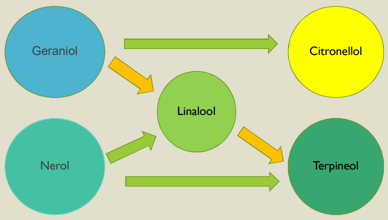
Compound	Aroma Attribute	% in Cascade Hop Oil Fraction	% in Citra Hop Oil Fraction	% in Saaz Hop Oil Fraction	% in Golding Hop Oil Fraction
Humulene	Noble aroma – "light"	8 – 13	11 – 13	15 – 25	38 - 44
Myrcene	Pungent, pine?	45 – 60	60 – 65	25 – 40	20 - 26
Caryophyllene	Clove, spicy	3 – 6	6 – 8	6 – 9	12 – 16
Farnesene	Woody, vegetative, "green"	3 – 7	0 – 1	14 - 20	0 - 1

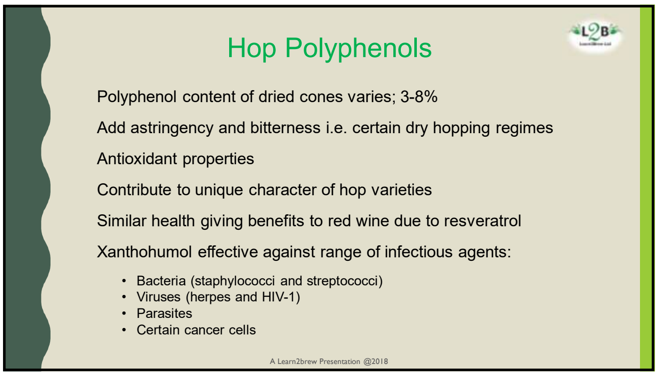
Essential Oils – Oxygenated Compounds

Compound	Aroma Attribute
Linalool	Floral, citrus
Geraniol	Floral, rose like
3M4MPA	Rhubarb
4MMP	Blackcurrant, passionfruit
Nerol	Floral, lime
3MH	Blackcurrant, muscat
Ethyl 2-methyl-butanoate	Fruity, apple
2 Methylbutyl isobutyrate	Sauvignon Blanc

Impact of Yeast Metabolism on Hop Oils

Action of yeast impacts on hop flavour via re-arrangement reactions during fermentation via reduction, hydrolysis and enzymatic processes.





Hop Polyphenols

Polyphenol content of dried cones varies; 3-8%

Add astringency and bitterness i.e. certain dry hopping regimes

Antioxidant properties

Contribute to unique character of hop varieties

Similar health giving benefits to red wine due to resveratrol

Xanthohumol effective against range of infectious agents:

- Bacteria (staphylococci and streptococci)
- Viruses (herpes and HIV-1)
- Parasites
- Certain cancer cells

A Learn2brew Presentation @2018

BEER BREAK!

HOPPING REGIMES

First Wort Hopping

Preis and Mitter publish a paper in 1995

Indicates the addition of 35% of total aroma hops pre-boil seemingly improved hop character. T45 pellets were used and added to the copper as soon as the bottom of the vessel was covered with liquid – Pellets not stirred or roused.

Trained tasters found the subsequent beers:

- To have a fine unobtrusive hop aroma
- To have a more harmonic nature
- To have a more uniform bitterness

Table 8 Concentrations of aroma substances µg/l brewery B

	Linalool	Terpineol	Geraniol	Humulene epoxide	Hexanol	Ethyl octanoate	Phenylethyl acetate
Reference wort	24.7	6.3	12.0	25.5	-	-	-
First wort hopped wort	1.2	-	11.0	6.9	-	-	-
Reference beer	34.1	5.3	14.6	10.8	15.2	110	584
First wort hopped beer	6.4	-	13.7	9.8	15.8	118	606

First Wort Hopping

Further research by Christina Hahn and Thomas Shellhammer, 2016

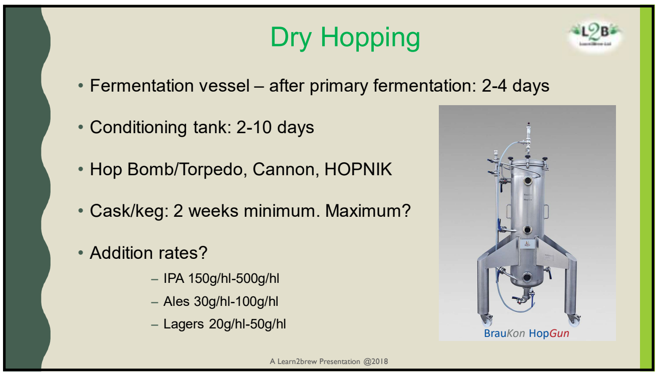
- Two worts; prepared using recipe designed to replicate American pale ale made with Cascade hops.
- Resulting brews differed only timing hop additions.
- FWH beer prepared by adding hops to the kettle before pump-over.
- FWH technique exposed hop material to warm wort at a pH of 5.35 for approximately 100 minutes prior to boil.
- Over course of pump-over, the initial wort temperature ranged from 57.8 to 55.9C and the concentration changed from 17.6 to 15.5 Plato prior to adjustment to 12P pre-boil.
- The control beer was prepared by adding hops at start of boil.
- Chemical characteristics for both worts were approximately the same.

First Wort Hopping

Further research by Christina Hahn and Thomas Shellhammer, 2016

Their conclusions:

- Chemical analysis showed minute differences between the two beers with the exception of their total polyphenol content (TPP) and foam stability.
- FWH beer was slightly higher in TPP compared to the control.
- Suggests that the FWH technique may influence extraction of polyphenolic material.
- Probable that the increased contact time between the hops and wort during FWH would increase levels of water soluble polyphenols, leading to an increase in TPP.
- However, the slight differences in TPP concentrations did not appear to influence the sensory perception of finished beer. Sensory discrimination testing showed no difference.
- Lack of difference chemically and sensorally leaves little argument for use of FWH technique
- Reduced foam stability observed in the FWH beer may prove to be a deterrent to many brewers.



Dry Hopping

- Fermentation vessel – after primary fermentation: 2-4 days
- Conditioning tank: 2-10 days
- Hop Bomb/Torpedo, Cannon, HOPNIK
- Cask/keg: 2 weeks minimum. Maximum?
- Addition rates?
    - IPA 150g/hl-500g/hl
    - Ales 30g/hl-100g/hl
    - Lagers 20g/hl-50g/hl

BrauKon HopGun

Dry Hopping Using Rolec System

Dry Hopping: Some Variables

Oil content – apparently not!

Temperature (More so for alpha acids)

ABV (Cold ethanol extraction)

Quantity (More not necessarily better)

Timing of addition

Length of contact

pH

Form of addition: cones, pellets, slurry

Size of hop particle (suspension)

Condition of lupulin glands

Losses through CO_2

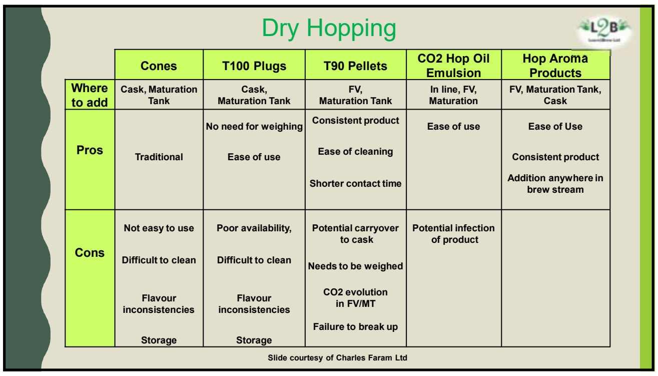
Yeast presence and count

Yeast type

Agitation (Both good & bad)

Hop variety and age

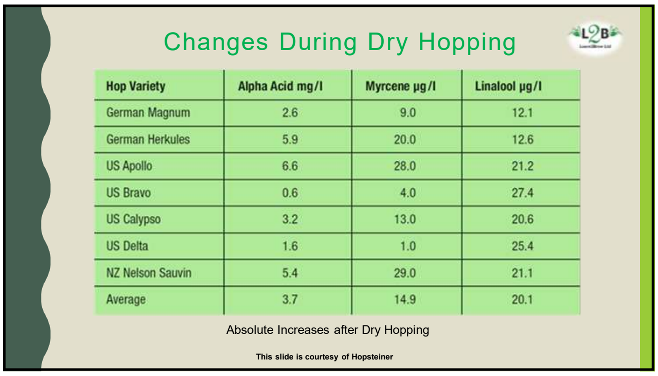
Humulinone level



Dry Hopping

	Cones	T100 Plugs	T90 Pellets	CO2 Hop Oil Emulsion	Hop Aroma Products
Where to add	Cask, Maturation Tank	Cask, Maturation Tank	FV, Maturation Tank	In line, FV, Maturation	FV, Maturation Tank, Cask
Pros	Traditional	No need for weighing Ease of use	Consistent product Ease of cleaning Shorter contact time	Ease of use	Ease of Use Consistent product Addition anywhere in brew stream
Cons	Not easy to use Difficult to clean Flavour inconsistencies Storage	Poor availability, Difficult to clean Flavour inconsistencies Storage	Potential carryover to cask Needs to be weighed CO2 evolution in FV/MT Failure to break up	Potential infection of product	

Slide courtesy of Charles Faram Ltd



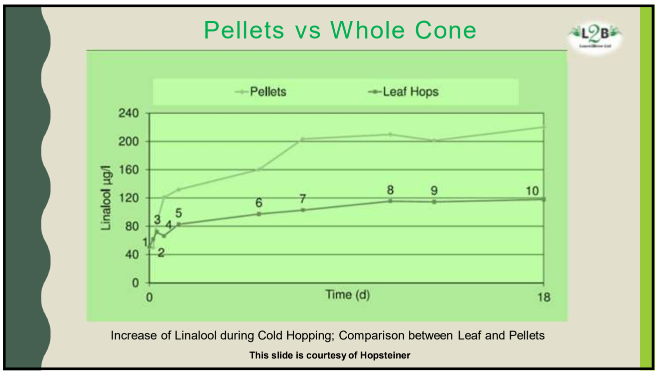
Changes During Dry Hopping

Hop Variety	Alpha Acid mg/l	Myrcene µg/l	Linalool µg/l
German Magnum	2.6	9.0	12.1
German Herkules	5.9	20.0	12.6
US Apollo	6.6	28.0	21.2
US Bravo	0.6	4.0	27.4
US Calypso	3.2	13.0	20.6
US Delta	1.6	1.0	25.4
NZ Nelson Sauvin	5.4	29.0	21.1
Average	3.7	14.9	20.1

Absolute Increases after Dry Hopping

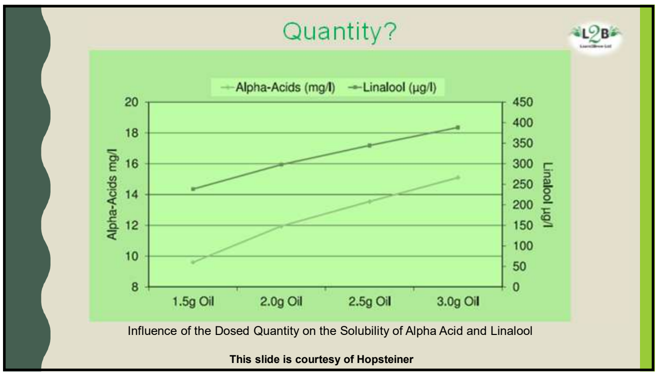
This slide is courtesy of Hopsteiner

Pellets vs Whole Cone



Increase of Linalool during Cold Hopping; Comparison between Leaf and Pellets

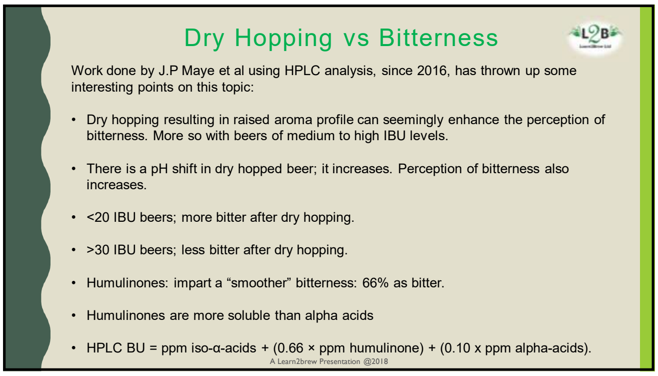
This slide is courtesy of Hopsteiner



Quantity?

Influence of the Dosed Quantity on the Solubility of Alpha Acid and Linalool

This slide is courtesy of Hopsteiner

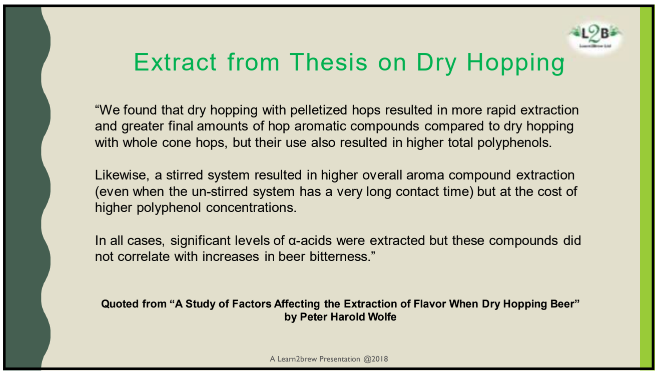


Dry Hopping vs Bitterness

Work done by J.P Maye et al using HPLC analysis, since 2016, has thrown up some interesting points on this topic:

- Dry hopping resulting in raised aroma profile can seemingly enhance the perception of bitterness. More so with beers of medium to high IBU levels.
- There is a pH shift in dry hopped beer; it increases. Perception of bitterness also increases.
- <20 IBU beers; more bitter after dry hopping.
- >30 IBU beers; less bitter after dry hopping.
- Humulinones: impart a “smoother” bitterness: 66% as bitter.
- Humulinones are more soluble than alpha acids
- HPLC BU = ppm iso-α-acids + (0.66 × ppm humulinone) + (0.10 x ppm alpha-acids).

A Learn2brew Presentation @2018



Extract from Thesis on Dry Hopping

“We found that dry hopping with pelletized hops resulted in more rapid extraction and greater final amounts of hop aromatic compounds compared to dry hopping with whole cone hops, but their use also resulted in higher total polyphenols.

Likewise, a stirred system resulted in higher overall aroma compound extraction (even when the un-stirred system has a very long contact time) but at the cost of higher polyphenol concentrations.

In all cases, significant levels of α-acids were extracted but these compounds did not correlate with increases in beer bitterness.”

Quoted from “A Study of Factors Affecting the Extraction of Flavor When Dry Hopping Beer” by Peter Harold Wolfe

A Learn2brew Presentation @2018

Other Changes During Dry Hopping

Brown and Morris had noted back in 1893 (Journal Institute of Brewing) that hops contain a percentage (~3%) of glucose and fructose which was also shown be fermented after extraction from the hops and in the presence of yeast.

In 1941 an article in the Journal of the Institute of Brewing in 1941 by J. Janicki (with W. V. Kotasthane, A. Parker, and T. K. Walker) questioned the presence of diastatic activity in hops and subsequent impact on secondary fermentation in cask beer.

In 2017, Kaylyn Kirkpatrick of Oregon State University in conjunction with Allagash Brewing Co. record and document the action of dry hopping with pellets and subsequent effect on CO_2 volumes.

In 2018 Dr. Lee Walsh of QCL Scientific produces a paper following research in conjunction with Northern Monk Brewery on ABV creep.

Dry Hopping: ABV% Creep

Method & Results

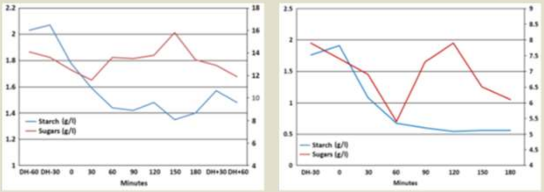
For the study, a sample was taken from the FV every 30 minutes, with two samples taken before dry-hopping and two samples taken after dry-hopping. All three beers were dry-hopped for 3-hours using a hop rocket and all samples taken were analysed for ABV, Fermentable Sugars (g/L), Starch (g/L), pH, and Bitterness (IBU) using the CDR BeerLab. The starch measured on the BeerLab will include a mixture of complex starch molecules not broken down in the Mash as well as some longer chain dextrin molecules. Fermentable Sugars is a measure of Glucose, Fructose, Maltose and Maltotriose.

Table 1. Dry-hop addition rate and alpha acid %

Beer	Addition Rate	Hop #1	Hop #2	Hop #3
Session IPA	3.5 g/L	11.2%	10.0%	8.1%
American IPA	4.0 g/L	7.2%	15.6%	14.6%
Double IPA	6.0 g/L	12.8%	10.6%	15.4%

Source: Dr Lee Walsh

Dry Hopping: ABV% Creep



American IPA (Left) and DIPA (Right)

The two most notable results came from the American IPA and the DIPA as expected, both beers showing high initial starch which drops as fermentable sugars increase. As shown in Figures 1 and 2 the American IPA has a starch concentration beginning around 2 g/L and dropping to a level of around 1.5 g/L, this drop is exaggerated in the DIPA with a drop from around 1.8 g/L to just over 0.5 g/L.

Source: Dr Lee Walsh

HOP PRODUCTS

Hop Products

Whole hops are bulky therefore an expensive product to transport and store.

Whole hops can be processed and transformed to reduce their size, whilst providing additional benefits including:

- Increased bulk density/ decreased volume.
- Improved convenience/ storage.
- Improved stability/ shelf life.
- Increased utilisation.
- Improved consistency/ homogeneity.
- Easier, automatic addition.
- Reduced extract loss/ effluent.
- Removal of unwanted elements (chemical residues/heavy metals).

Hop Products

Non isomerised products – containing **alpha acid**:

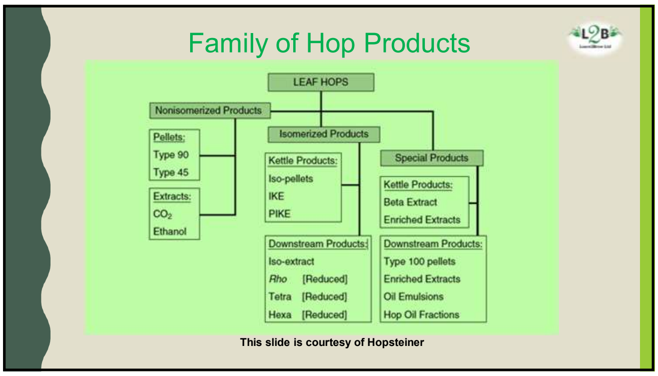
- Whole cone hops Type 100
- Pelletised hops Type 90
- Enriched pelletised hops Type 45
- Hop kettle extracts

Not isomerised so they have to be boiled; added to the kettle

Isomerised products – containing **iso-alpha acid:**

- Isomerised pellets
- Isomerised Kettle extracts
- Isomerised post fermentation bitterness (extract)
- Reduced hop compounds

Since isomerisation has taken place outside the kettle they can be added a later stage in the brewing process.



Family of Hop Products

LEAF HOPS

Nonisomerized Products

Pellets:
Type 90
Type 45

Extracts:
CO_2
Ethanol

Isomerized Products

Kettle Products:
Iso-pellets
IKE
PIKE

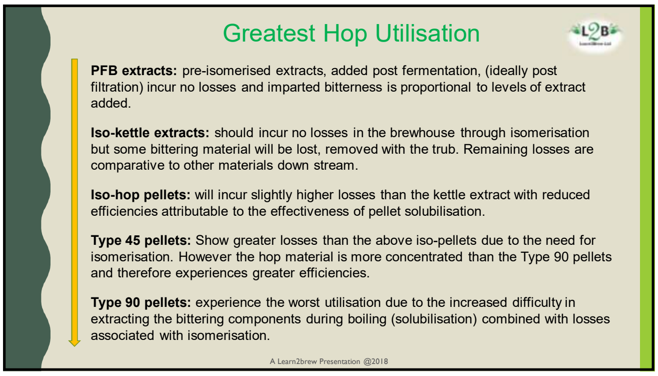
Downstream Products:
Iso-extract
Rho [Reduced]
Tetra [Reduced]
Hexa [Reduced]

Special Products

Kettle Products:
Beta Extract
Enriched Extracts

Downstream Products:
Type 100 pellets
Enriched Extracts
Oil Emulsions
Hop Oil Fractions

This slide is courtesy of Hopsteiner



Greatest Hop Utilisation

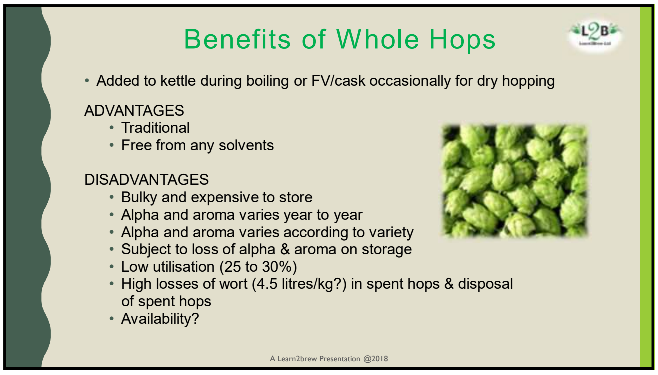
PFB extracts: pre-isomerised extracts, added post fermentation, (ideally post filtration) incur no losses and imparted bitterness is proportional to levels of extract added.

Iso-kettle extracts: should incur no losses in the brewhouse through isomerisation but some bittering material will be lost, removed with the trub. Remaining losses are comparative to other materials down stream.

Iso-hop pellets: will incur slightly higher losses than the kettle extract with reduced efficiencies attributable to the effectiveness of pellet solubilisation.

Type 45 pellets: Show greater losses than the above iso-pellets due to the need for isomerisation. However the hop material is more concentrated than the Type 90 pellets and therefore experiences greater efficiencies.

Type 90 pellets: experience the worst utilisation due to the increased difficulty in extracting the bittering components during boiling (solubilisation) combined with losses associated with isomerisation.

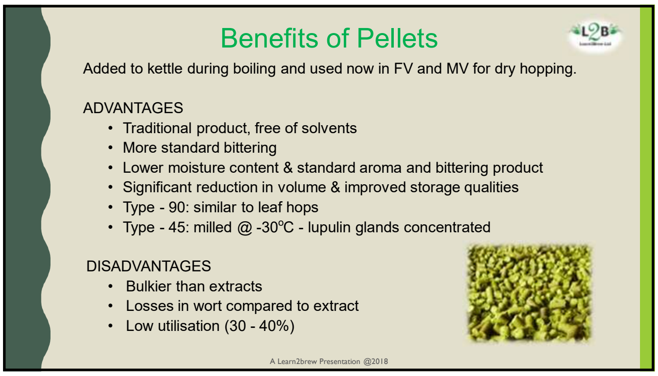


Benefits of Whole Hops

- Added to kettle during boiling or FV/cask occasionally for dry hopping

ADVANTAGES
  - Traditional
  - Free from any solvents

DISADVANTAGES
  - Bulky and expensive to store
  - Alpha and aroma varies year to year
  - Alpha and aroma varies according to variety
  - Subject to loss of alpha & aroma on storage
  - Low utilisation (25 to 30%)
  - High losses of wort (4.5 litres/kg?) in spent hops & disposal of spent hops
  - Availability?



Benefits of Pellets

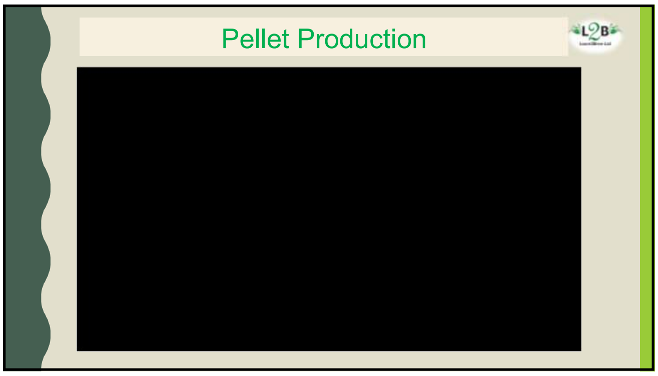
Added to kettle during boiling and used now in FV and MV for dry hopping.

ADVANTAGES

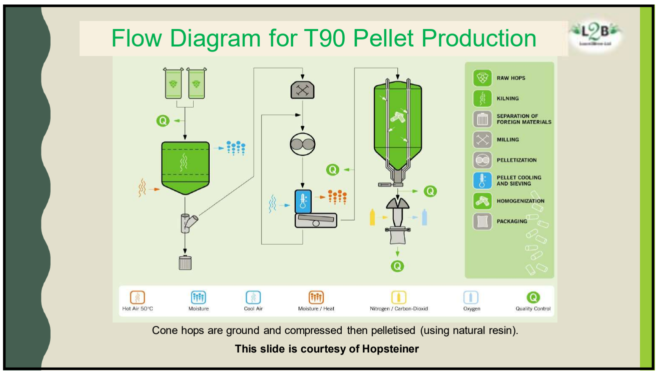
- Traditional product, free of solvents
- More standard bittering
- Lower moisture content & standard aroma and bittering product
- Significant reduction in volume & improved storage qualities
- Type - 90: similar to leaf hops
- Type - 45: milled @ -30°C - lupulin glands concentrated

DISADVANTAGES

- Bulkier than extracts
- Losses in wort compared to extract
- Low utilisation (30 - 40%)



Pellet Production



Flow Diagram for T90 Pellet Production

Cone hops are ground and compressed then pelletised (using natural resin).

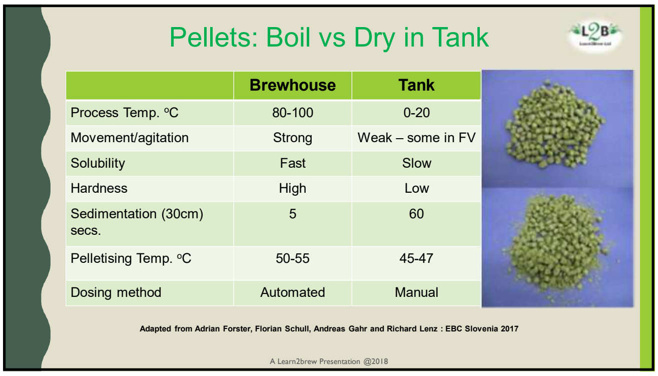
This slide is courtesy of Hopsteiner

Pellets: Boil vs Dry in Tank

General concerns regarding pellet quality:

- Brewers often prefer pellets with a high stability without fine powder particles; hard pellets are more advantageous in some dosing systems.
- Stable pellets produced in pellet mill at higher temperatures: Negative impact on product quality.
- Brewer has to accept and find a compromise between hard pellets pressed at higher temperatures and soft pellets, with a higher ratio of fines, at lower pelletisation temperature.
- Dry hopping in a tank the pellet specifications are different to those dosed in the brewhouse:
  - They should be softer for a faster disintegration time, which also allows a pelletisation at reduced temperatures and thus a production of a high aroma quality pellet.
  - A smaller particle size is also an advantage when dosing pellets into a tank. They sediment slower and enable a better extraction.

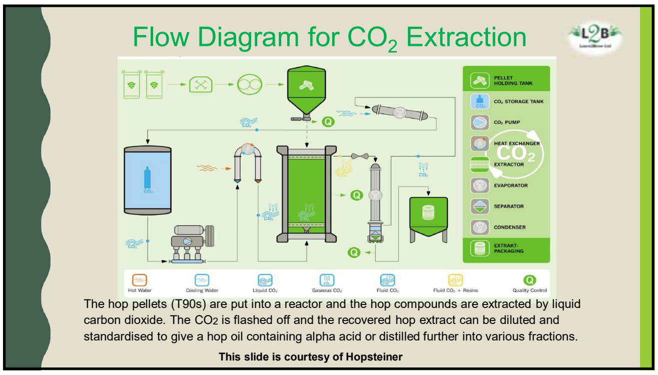
Adapted from Adrian Forster, Florian Schull, Andreas Gahr and Richard Lenz : EBC Slovenia 2017



Pellets: Boil vs Dry in Tank

	Brewhouse	Tank
Process Temp. ºC	80-100	0-20
Movement/agitation	Strong	Weak – some in FV
Solubility	Fast	Slow
Hardness	High	Low
Sedimentation (30cm) secs.	5	60
Pelletising Temp. ºC	50-55	45-47
Dosing method	Automated	Manual

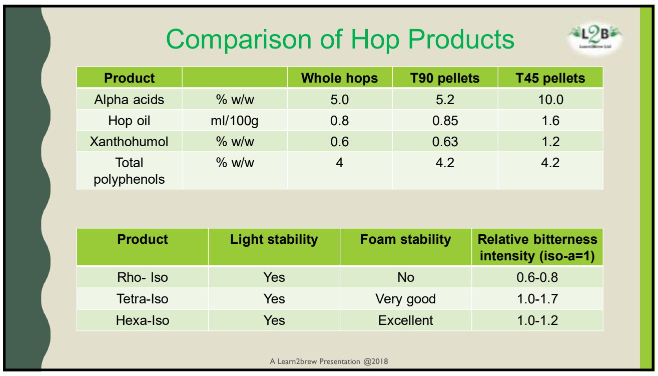
Adapted from Adrian Forster, Florian Schull, Andreas Gahr and Richard Lenz : EBC Slovenia 2017



Flow Diagram for CO_2 Extraction

The hop pellets (T90s) are put into a reactor and the hop compounds are extracted by liquid carbon dioxide. The CO2 is flashed off and the recovered hop extract can be diluted and standardised to give a hop oil containing alpha acid or distilled further into various fractions.

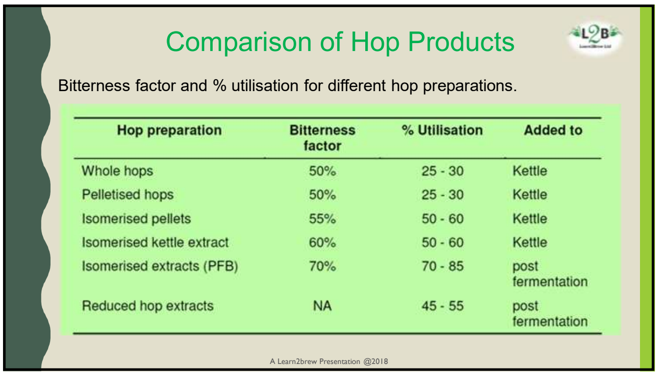
This slide is courtesy of Hopsteiner



Comparison of Hop Products

Product		Whole hops	T90 pellets	T45 pellets
Alpha acids	% w/w	5.0	5.2	10.0
Hop oil	ml/100g	0.8	0.85	1.6
Xanthohumol	% w/w	0.6	0.63	1.2
Total polyphenols	% w/w	4	4.2	4.2

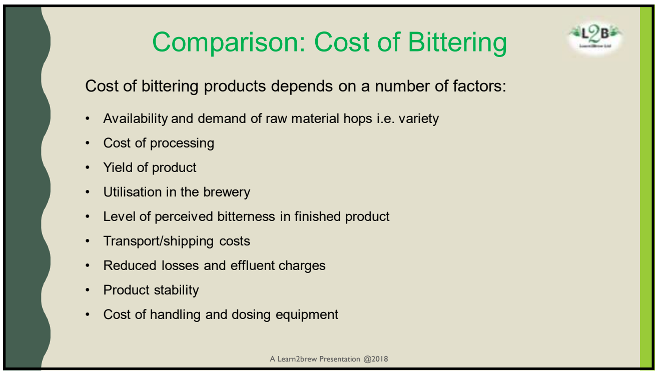
Product	Light stability	Foam stability	Relative bitterness intensity (iso-a=1)
Rho- Iso	Yes	No	0.6-0.8
Tetra-Iso	Yes	Very good	1.0-1.7
Hexa-Iso	Yes	Excellent	1.0-1.2



Comparison of Hop Products

Bitterness factor and % utilisation for different hop preparations.

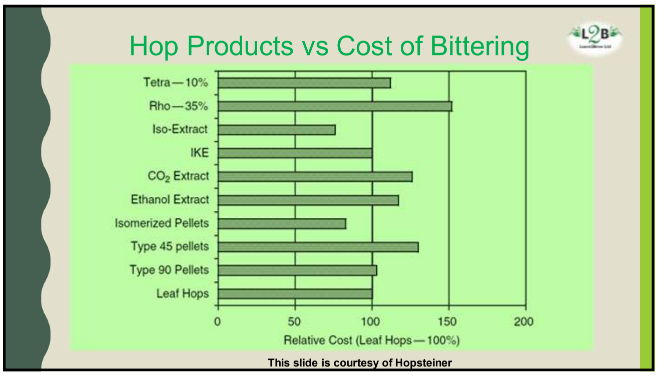
Hop preparation	Bitterness factor	% Utilisation	Added to
Whole hops	50%	25 - 30	Kettle
Pelletised hops	50%	25 - 30	Kettle
Isomerised pellets	55%	50 - 60	Kettle
Isomerised kettle extract	60%	50 - 60	Kettle
Isomerised extracts (PFB)	70%	70 - 85	post fermentation
Reduced hop extracts	NA	45 - 55	post fermentation



Comparison: Cost of Bittering

Cost of bittering products depends on a number of factors:

- Availability and demand of raw material hops i.e. variety
- Cost of processing
- Yield of product
- Utilisation in the brewery
- Level of perceived bitterness in finished product
- Transport/shipping costs
- Reduced losses and effluent charges
- Product stability
- Cost of handling and dosing equipment



Hop Products vs Cost of Bittering

This slide is courtesy of Hopsteiner

Thank You.

Any Questions?

Learn2Brew Ltd

A Learn2brew Presentation @2018