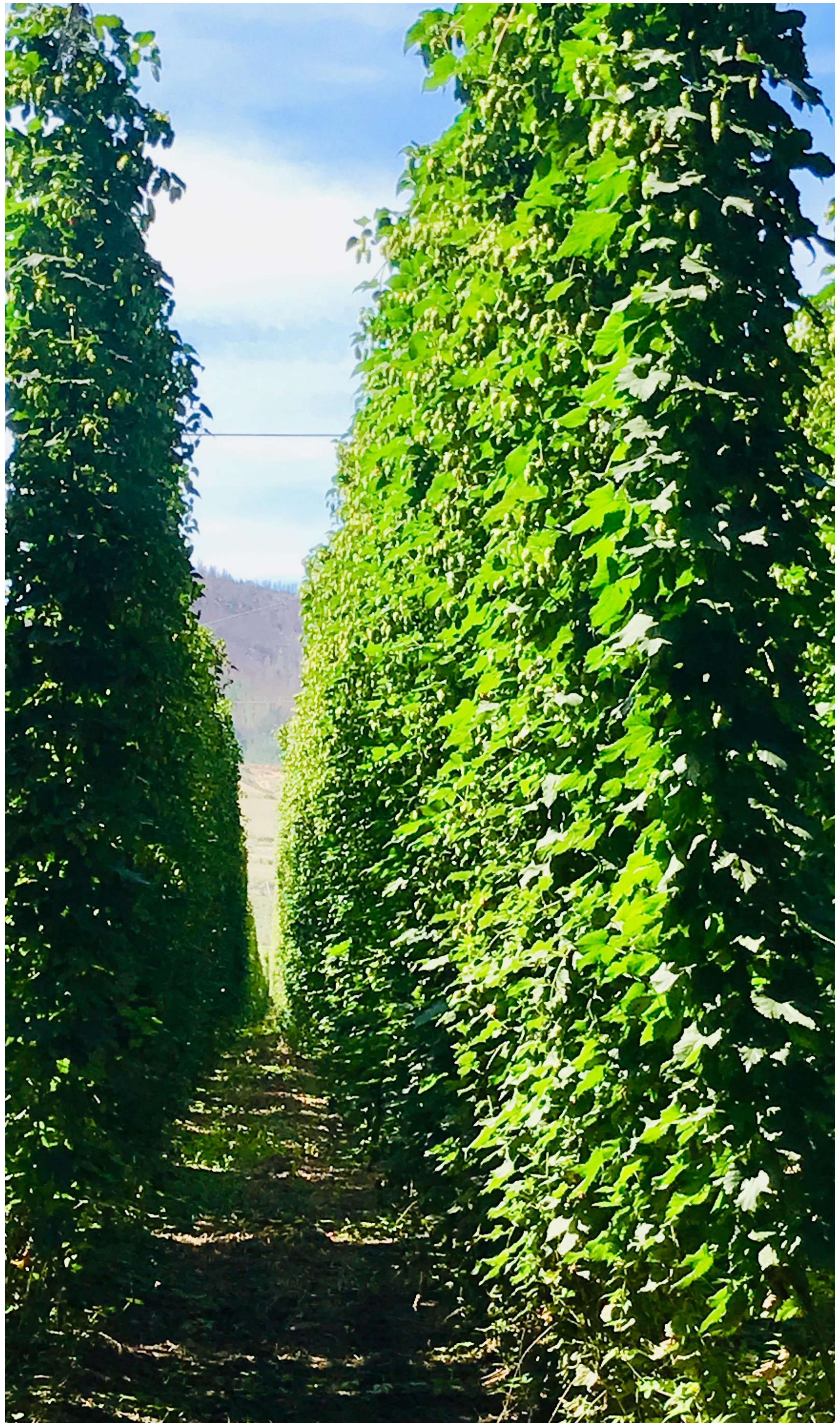

Preserve
BOTanica
SPECIALIZED BOTANICAL PREPARATIONS

Sustainable Development of Upcycled Hop Oils from African Variety Hop Co-Product

1. Upcycling as a strategy for sustainable supply chains
2. Preserve Botanica Case Study in the Hop Industry
3. Key Takeaways

Wasted Opportunities


Preserve
BOTANICA
SPECIALIZED BOTANICAL PREPARATIONS
Agricultural Waste: Re-think and re-use

nature communications

Article

https://doi.org/10.1038/s41467-026-72379-8

Extensive variation between chromosomes of North American and European hop

Received: 11 July 2025

Accepted: 15 April 2026

Published online: 27 May 2026

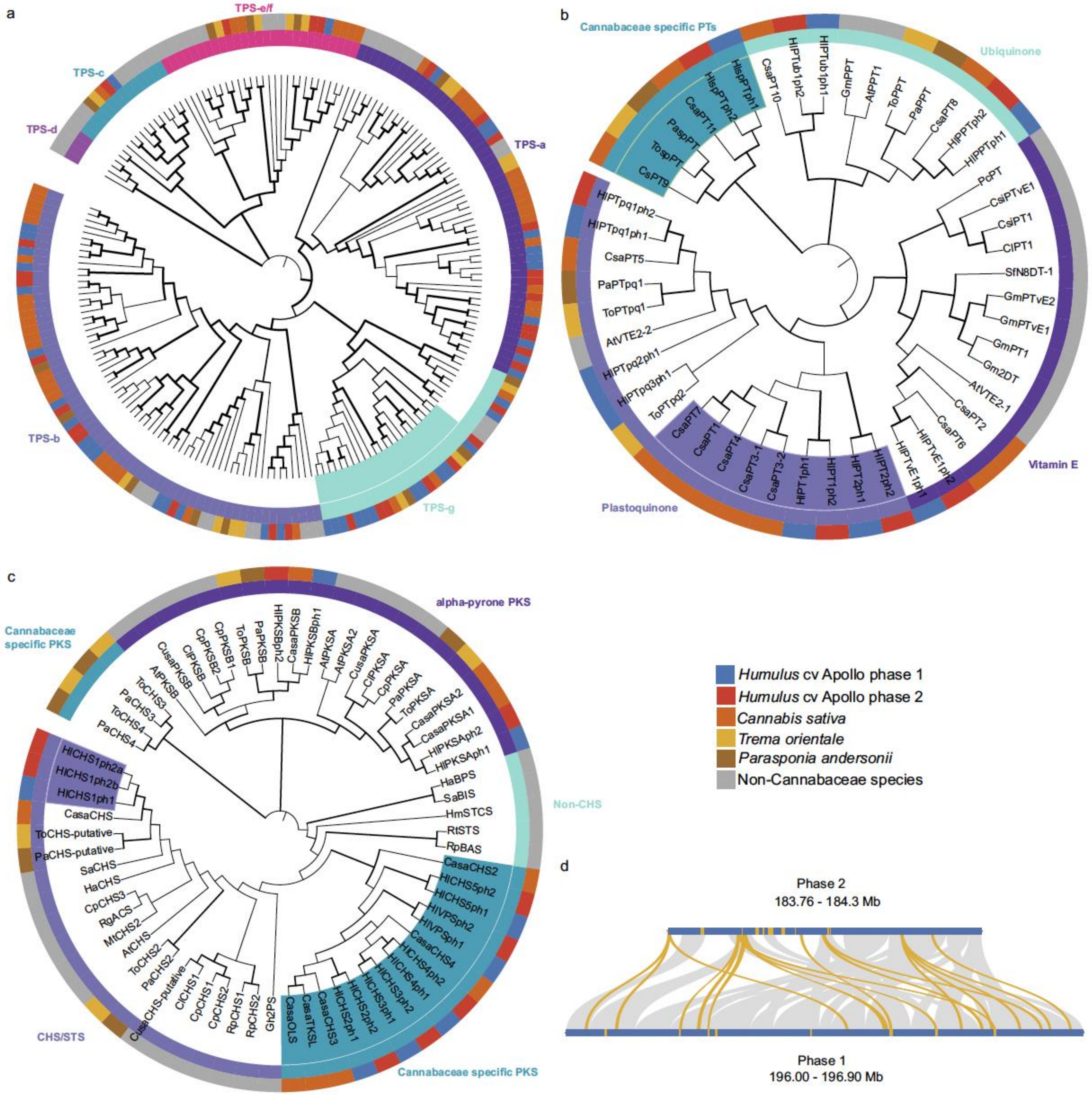
Check for updates

Sandip Mallikarjun Kale[1,15,16], Heidrun Gundlach[2,16], Oliver Gericke[1,16], Nadia Kamal[2,3], Aldo Almeida[1], Nicholi Pitra[4], Nicholas Price[4], Georg Haberer[2], Thomas Lux[2], Flavia Krsticevic[1], Oliver Kemp[1], Louise de Bang[1], Axel Himmelbach[5], Sudharsan Padmarasu[5], Mark-Timothy Rabanus-Wallace[5], Lucie Horáková[6], Václav Bačovský[6], Kasper Nielsen[1], Nanna Bjarnholt[7,8], Nikola Micic[7,8], Isabella Kruse-Andersen[1,7], Birger Lindberg Møller[7,8], Christian Janfelt[9], Birgitte Skadhauge[1], Paul D. Matthews[4], Klaus F. X. Mayer[2,10], Nils Stein[5,11], Martin Mascher[5,12], Manuel Spannagl[2,13], Alexander Feiner[14] & Ilka Braumann[1]

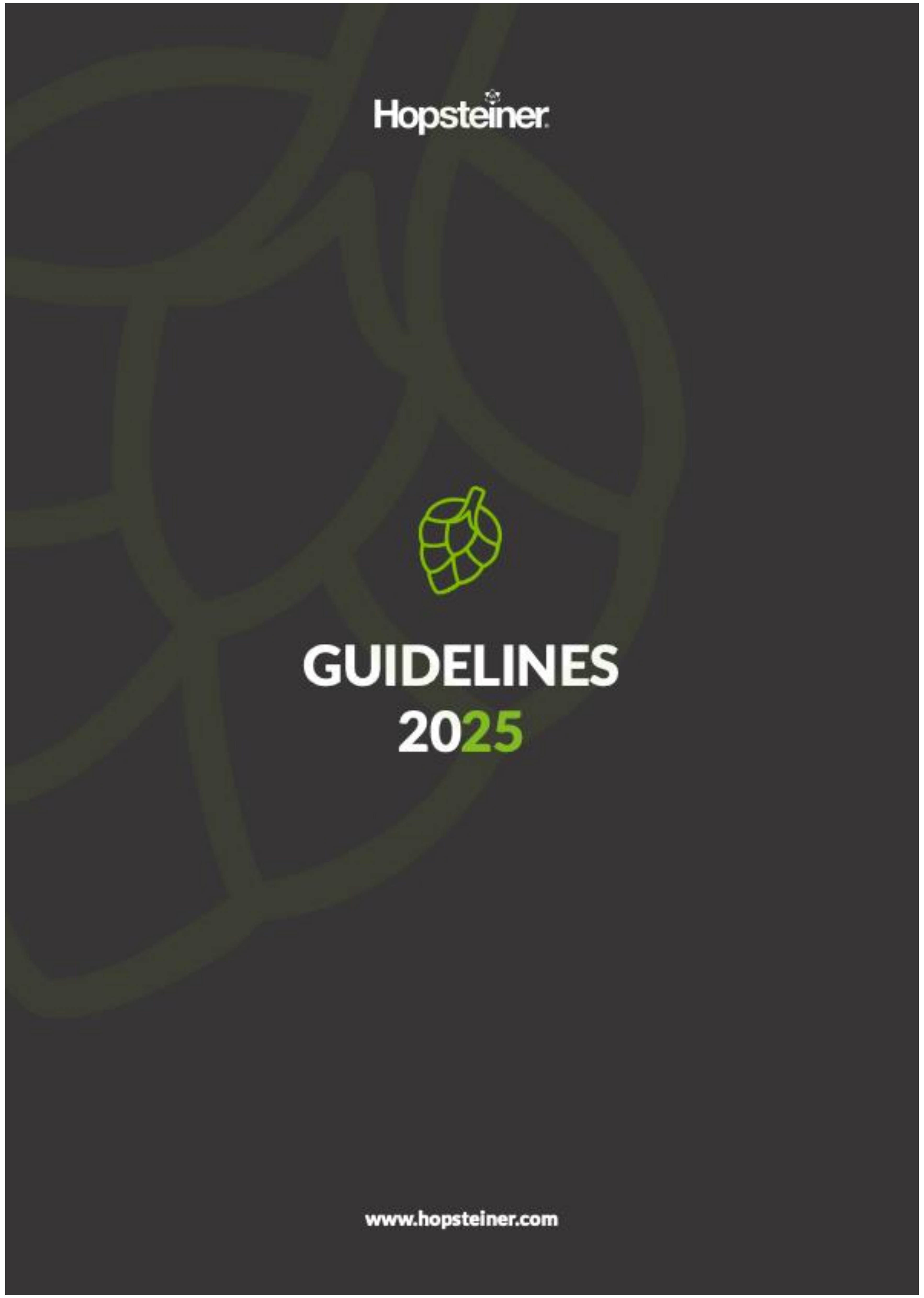
Hop is an essential ingredient in brewing, providing beer with its characteristic bitterness and aroma. Most modern hop cultivars are hybrids between European and North American hop lineages, but how these ancestries contribute to bitter acid content, the most important trait in hop breeding, remains unclear. Here, we report chromosome-scale, haplotype-resolved assemblies of the hybrid hop cultivar Apollo, assign European and North American ancestry across the genome, and identify varying levels of recombination suppression between chromosomes of either origin. Using this reference, we uncover genetic and chemical diversity in core bittering pathways between European and North American hops. We further show additive effects of beneficial European and North American alleles on bitter acid content, providing a foundation for genomics-assisted hop breeding.

Female plants of *Humulus spp.* L. (hop), member of the Cannabaceae family and sister to the genus *Cannabis*, have been cultivated for their cones (hops) since at least A.D. 859 when the practice of adding hops into beer developed in medieval Central Europe[1]. Hops contain α-acids that lend a characteristic bitter taste and, more importantly, made beer a durable food item suitable for transport and trade. After the mid-14th century, the demand for beer increased. It was preferred over water, as the latter was often polluted. Brewing became a professional craft and

[1]Carlsberg Research Laboratory, Copenhagen, Denmark. [2]Helmholtz Munich – German Research Center for Environmental Health, Plant Genome and Systems Biology (PGSB), Neuherberg, Germany. [3]Technical University of Munich, TUM School of Life Sciences, Computational Plant Biology, Freising, Germany. [4]Hopsteiner, S.S. Steiner, Inc, New York, NY, USA. [5]Leibniz Institute of Plant Genetics and Crop Plant Research (IPK) Gatersleben, Seeland, Germany. [6]Department of Plant Developmental Genetics, Institute of Biophysics of the Czech Academy of Sciences, Brno, Czechia. [7]Department of Plant and Environmental Sciences, Section for Plant Biochemistry, University of Copenhagen, Frederiksberg, Denmark. [8]Department of Plant and Environmental Sciences, Copenhagen Plant Science Center, University of Copenhagen, Frederiksberg, Denmark. [9]Department of Pharmacy, University of Copenhagen, Copenhagen, Denmark. [10]School of Life Sciences, Technical University Munich, Freising, Germany. [11]Institute of Agricultural and Nutritional Sciences, Martin Luther University Halle-Wittenberg, Halle, Germany. [12]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany. [13]Centre for Crop and Food Innovation, Food Futures Institute, Murdoch University, Perth, WA, Australia. [14]Hopsteiner, Simon H. Steiner, Hopfen, GmbH, Mainburg, Germany. [15]Present address: Department of Agroecology, Aarhus University, Slagelse, Denmark. [16]These authors contributed equally: Sandip Mallikarjun Kale, Heidrun Gundlach, Oliver Gericke. e-mail: manuel.spannagl@helmholtz-munich.de; alexander.feiner@hopsteiner.de; ilka.braumann@carlsberg.com

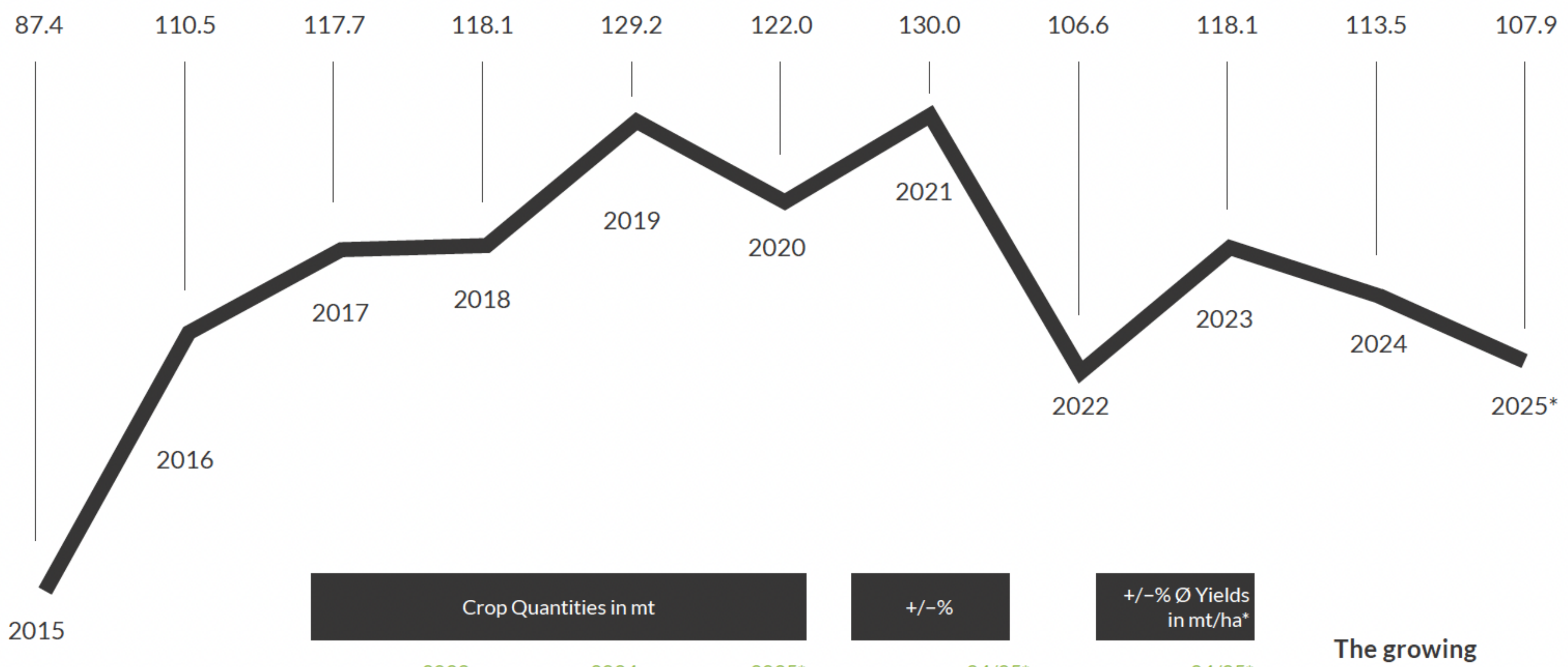


a
TPS-e/f
TPS-c
TPS-d
TPS-a
TPS-b
TPS-g
b
Cannabaceae specific PTs
Ubiquinone
Vitamin E
Plastoquinone
HlspPTph1
HlspPTph2
CsaPT11
PaspPT
TospPT
CsPT9
CsaPT10
HlPTub1ph2
HlPTub1ph1
GmPPT
AtPPT1
ToPPT
PaPPT
CsaPT8
HlPPTph2
HlPPTph1
PcPT
CsiPTvE1
CsiPT1
ClPT1
SfN8DT-1
GmPTvE2
GmPTvE1
GmPT1
Gm2DT
AtVTE2-1
CsaPT2
CsaPT6
HlPTvE1ph2
HlPTvE1ph1
HlPT2ph2
HlPT2ph1
HlPT1ph2
HlPT1ph1
CsaPT3-2
CsaPT3-1
CsaPT4
CsaPT1
CsaPT7
ToPTpq2
HlPTpq3ph1
HlPTpq2ph1
AtVTE2-2
ToPTpq1
PaPTpq1
CsaPT5
HlPTpq1ph1
HlPTpq1ph2
c
Cannabaceae specific PKS
alpha-pyrone PKS
Non-CHS
CHS/STS
Cannabaceae specific PKS
PaCHS4
ToCHS4
PaCHS3
ToCHS3
AtPKSB
CusaPKSB
ClPKSB
CpPKSB2
CpPKSB1
ToPKSB
PaPKSB
HlPKSBph2
CasaPKSB
HlPKSBph1
AtPKSA
AtPKSA2
CusaPKSA
ClPKSA
CpPKSA
PaPKSA
ToPKSA
CasaPKSA2
CasaPKSA1
HlPKSAph2
HlPKSAph1
HaBPS
SaBIS
HmSTCS
RtSTS
RpBAS
CasaCHS2
HlCHS5ph2
HlCHS5ph1
HlVPSph2
HlVPSph1
CasaCHS4
HlCHS4ph2
HlCHS4ph1
HlCHS3ph2
HlCHS3ph1
HlCHS2ph2
HlCHS2ph1
CasaCHS3
CasaTKSL
CasaOLS
Gh2PS
RpCHS2
RpCHS1
CpCHS2
CpCHS1
ClCHS1
CusaCHS-putative
PaCHS2
ToCHS2
AtCHS
MtCHS2
RgACS
CpCHS3
HaCHS
SaCHS
PaCHS-putative
ToCHS-putative
CasaCHS
HlCHS1ph1
HlCHS1ph2b
HlCHS1ph2a
Humulus cv Apollo phase 1
Humulus cv Apollo phase 2
Cannabis sativa
Trema orientale
Parasponia andersonii
Non-Cannabaceae species
d
Phase 2
183.76 - 184.3 Mb
Phase 1
196.00 - 196.90 Mb



Crop Quantities and Average Yield

Total Hop Crop in mt (2015–2025)



	Crop Quantities in mt			+/–%	+/–% Ø Yields in mt/ha*
	2023	2024	2025*	24/25*	24/25*
Europe	59,097	62,846	59,616	–5.1	–0.5
Austria	380	330	478	+44.8	+45.1
Belgium	309	266	246	–7.5	–2.0
Czechia	6,998	6,494	6,909	+6.4	+6.7
England	776	776	651	–16.1	–6.9
France	917	960	853	–11.1	–8.6
Germany	41,233	46,536	43,142	–7.3	–0.4
Elbe-Saale	3,056	2,569	2,505	–2.5	+8.3
Hallertau	34,949	40,302	37,250	–7.6	–0.8
Spalt	672	717	615	–24.2	–5.5
Tettnang	2,533	2,908	2,724	–6.3	–5.8
Other areas	23	40	47	+17.5	+18.0
Poland	3,505	2,953	2,770	–6.2	–6.9
Romania	225	208	200	–3.8	–4.1
Russia	500	500	550	+10.0	–8.0
Slovenia	2,735	2,245	2,345	+4.5	+6.6
Spain	843	963	861	–10.6	–8.9
Turkey	240	230	230	0	0
Ukraine	160	158	158	0	0
Other European countries[1]	276	227	223	–1.8	–2.5
USA	47,306	39,608	36,830	–7.0	–0.9
Pacific Northwest	47,193	39,529	36,751	–7.0	+0.6
Other regions	113	79	79	0	+43.3
Other countries	11,732	11,025	11,494	+4.3	+7.1
Argentina	254	360	380	+5.6	+5.4
Australia	1,965	1,508	1.500	–0.5	+30.2
Japan	123	160	160	0	0
New Zealand	2,000	1,760	1,420	–19.3	0
PRChina	6,100	5,810	6,607	+13.7	+8.3
South Africa	740	682	682	0	0
Other states[2]	550	745	745	0	0
TOTAL	118,135	113,480	107,940	–4.9	0

The growing conditions in Europe were initially characterized by moderate temperatures and well below-average rainfall. Adequate precip-itation did not occur until mid-July, ultimately resulting in a good harvest.

Data source: IHGC

* Estimate

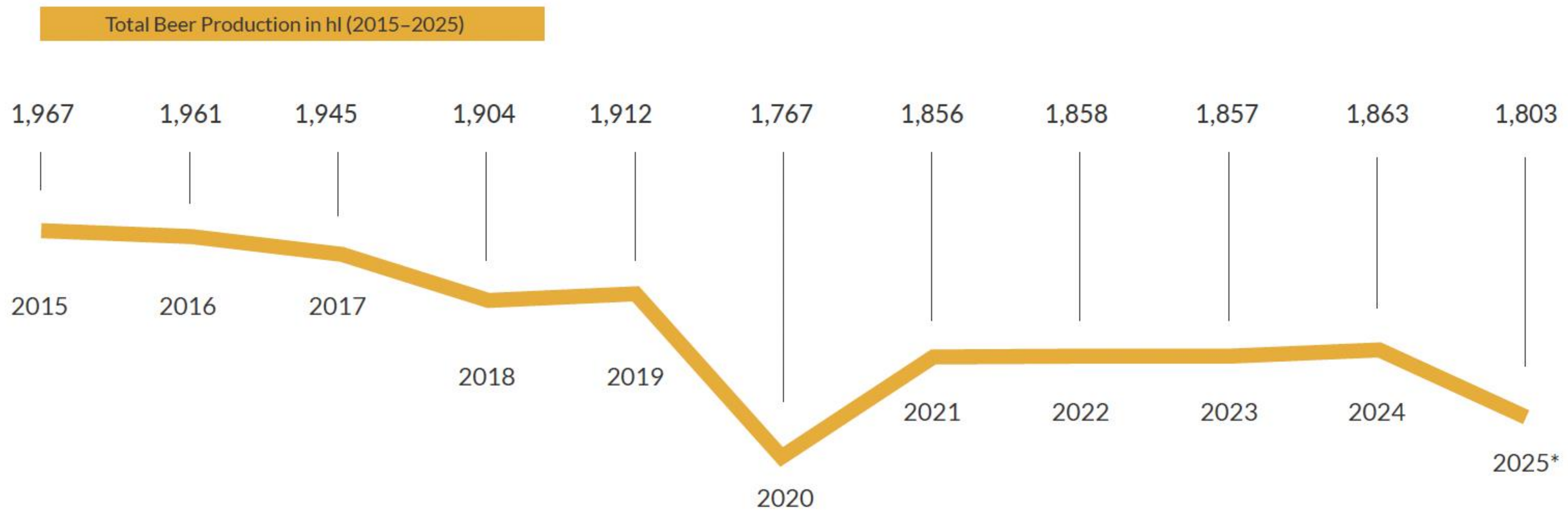
–4.9%

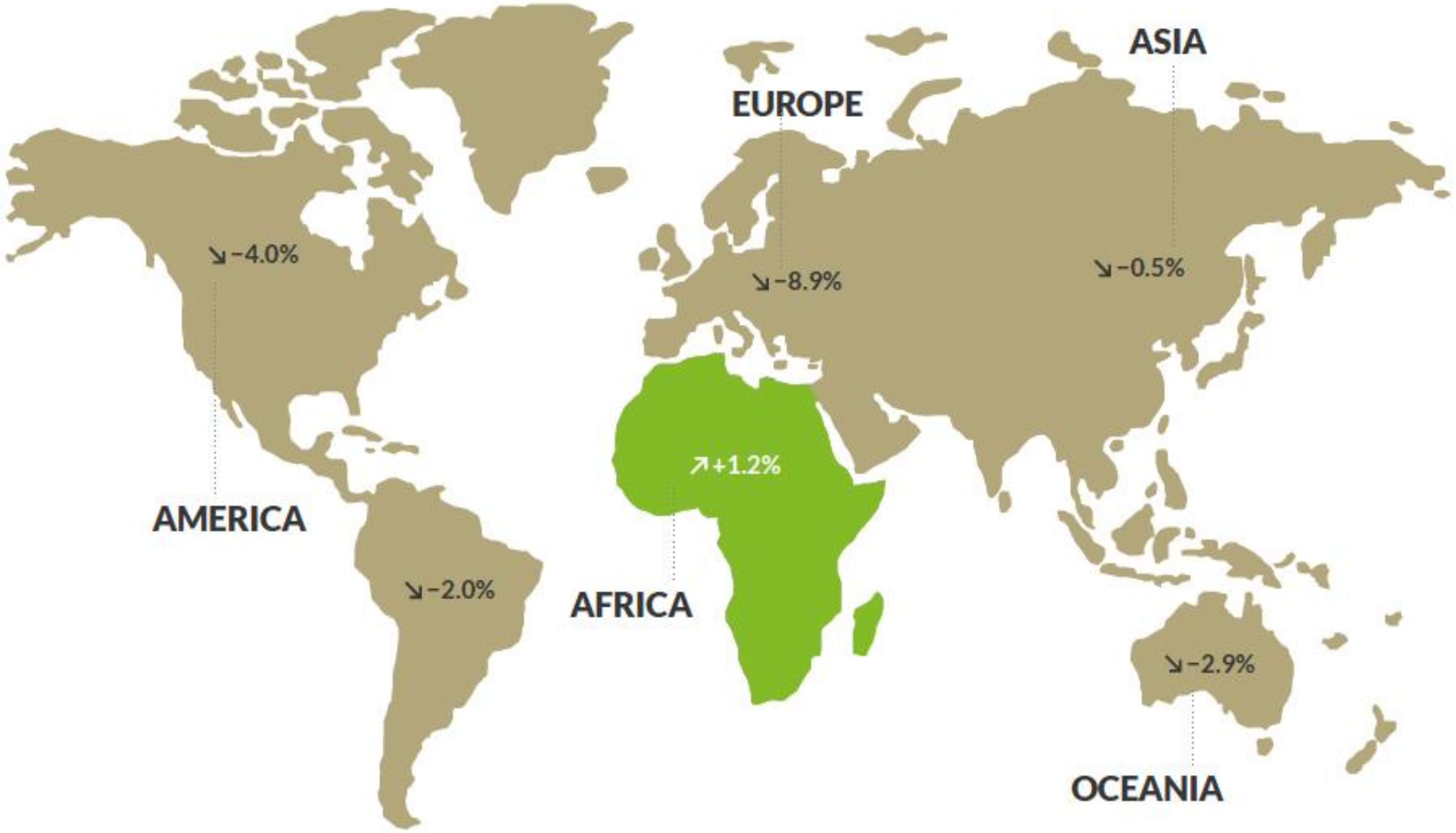
LESS WORLD HOP CROP COMPARED TO 2024

[1] Belarus, Bulgaria, Croatia, Hungary, Italy, Portugal, Serbia/Montenegro, Slovakia, Switzerland

[2] Brazil, Canada, India

World Beer Production






CARBON INTENSITY
WATER STEWARDSHIP
RESOURCE EFFICIENCY
CIRCULARITY
SUPPLY CHAIN RESILIENCE
ENVIRONMENTAL TRANSPARENCY
preserve
BOTANICA

Waboomskraal Valley

Preserve BOTANICA
SPECIALIZED BOTANICAL PREPARATIONS

+50%

accelerator 100+

Preserve BOTANICA
SPECIALIZED BOTANICAL PREPARATIONS

to preserve every part of hops


OCEANUS
OCEANUS
LITTLE DUCK

accelerator 100+

Welcome 46 selected startups for Cohort 4!

Aerodymax
AgriFriend
AKSELOS
AQUACYCL
amperehour
AtlasAI
BEEODIVERSITY regenerating value
DataMesh
Diversity Suppliers
done prop erly
EcoAct Tanzania
ekonoke
Elodys International
emrgy
evo lectric
evove
growPack
ICHTHION
Henoscene
Inspectral
Kelpy
KETOS
kran
LASSO
MODO RE
NANOFREEZE "A new way to refrigerate naturally"
NFINITE NANOTECH
NO Palm Ingredients
Passive Edge We Create Sustainability
preserve BOTANICA
QiO
REFILLABLE
REGENIZE
Salient
CONSERVATION X LABS
VEGATEX®
Shopa
SolarGik
Solumar
Uet
VIRENXIA
waterplan
SVARMI
zafree
60 _ dB
CLIMATENZA

Powered by

ABInBev
COLGATE-PALMOLIVE
THE Coca-Cola COMPANY
Unilever

accelerator 100+

IMPATIENT **OPTIMISTS**

Powered by

ABInBev · COLGATE-PALMOLIVE · THE Coca-Cola COMPANY · Unilever

accelerator 100+

Cohort 4 startups are collectively addressing

ALL OF THE 17 UN SDGs

Powered by

ABInBev · COLGATE-PALMOLIVE · THE Coca-Cola COMPANY · Unilever

accelerator 100+

18 Women Founders

18 Founders Under 30

+20 Spoken Languages

Powered by

ABInBev · COLGATE-PALMOLIVE · THE Coca-Cola COMPANY · Unilever


accelerator
100+
LIFE SAVING
RULES
CAUTION


Oil 17 L
28 Tons
Hydrosol
4 500
Pilot Results


Esters 24%


10,000 MILES
NEWLANDS SPRING BREWING CO.
LEGEND
PASSIONATE BLOND
NEWLANDS SPRING BREWING CO.
THE ORIGINAL SOURCE
ELYSIAN BREWING
BLUE/POINT
BREWING CO. 40.77,-73.02


accelerator
100+
ABInBev
THE
Coca-Cola
COMPANY
COLGATE-PALMOLIVE
Unilever

life

MDPI

Article

Comparison of Major Compounds in Essential Oils Steam Distilled from Fresh Plant Material of South African Hop Varieties

Olga de Smidt [1,*], Wanda du Plessis [2], Puleng Rose Zacharia [1] and Idah Tichaidza Manduna [1]

1 Centre for Applied Food Sustainability and -Biotechnology (CAFSaB), Central University of Technology (CUT), Bloemfontein 9300, South Africa; pzacharia@cut.ac.za (P.R.Z.); imanduna@cut.ac.za (I.T.M.)
2 Preserve Botanica PTY, Ltd., George 6529, South Africa; wanda@preservebotanica.co.za
* Correspondence: odesmidt@cut.ac.za; Tel.: +27-823-402-136

Abstract: Apart from the importance of bittering acids in the brewing sector, hops also produce terpene-rich essential oils, recognised for their therapeutic benefits. Agri-processing practices of this crop in South Africa produce tonnes of discarded (waste) plant material that could still contain sufficient bioactive compounds to justify upcycling. This research aimed to determine the chemical composition of steam distilled essential oils from fresh hop plant material destined for disposal. Essential oils from eight hop varieties unique to South Africa were produced on industrial scale using steam distillation. Chemical profiling was performed using GC-FID and MS. A total of 208 compounds were identified and oil consisted largely of terpenes (89.04 ± 1.89%) as well as aliphatic esters and -ketones (6.1 ± 1.15%). Myrcene (27.8–48.15%) was the most abundant monoterpene and α-humulene (19.52–24.98%), β-caryophyllene (8.47–13.73%) and β-farnesene (2.08–7.57%) constituted the majority of the sesquiterpenes fraction. Experimental variety XJA2/436 had the highest myrcene fraction (48.15%) and its chemical composition was markedly different from the other varieties. The major compounds in African Queen hop oil were methyl (4Z) decanoate (0.74%), 2-tridecanone (0.77%) and β-farnesene (7.57%). Southern Dawn hop oil contained the highest fractions of 2-undecanone (1.21%) and α-humulene (24.89%) and Southern Passion hop oil contained the highest β-caryophyllene fraction (13.73%). These findings established that fresh hop vegetative biomass shows promise to be transformed into a valuable resource.

Keywords: hops; hop essential oils; terpenes; GC-FID; GC-MS; aliphatic compounds; toxicity

check for updates

Academic Editor: Vaidotas Žvikas

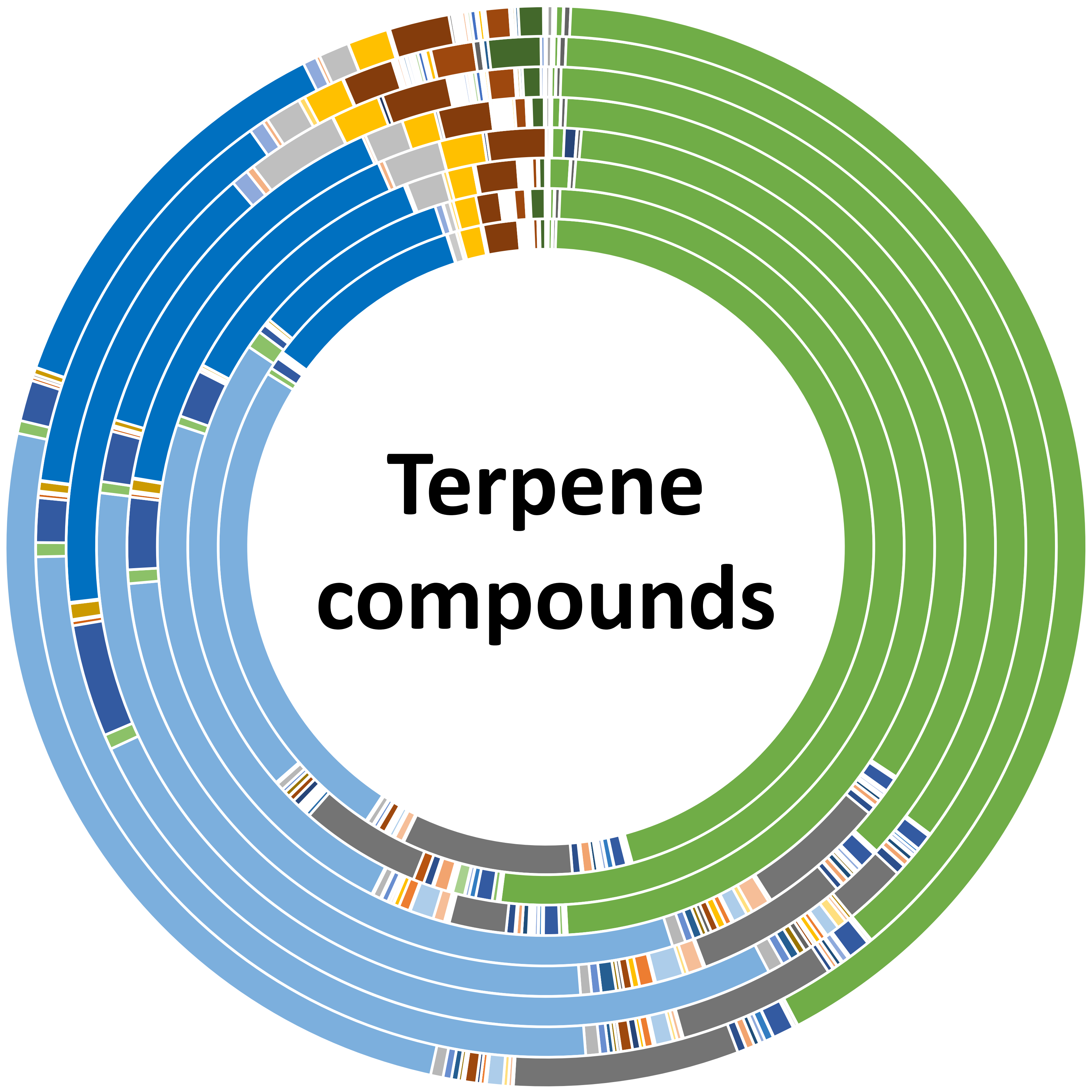
Received: 12 December 2024
Revised: 13 January 2025
Accepted: 29 January 2025
Published: 12 February 2025

Citation: de Smidt, O.; du Plessis, W.; Zacharia, P.R.; Manduna, I.T. Comparison of Major Compounds in Essential Oils Steam Distilled from Fresh Plant Material of South African Hop Varieties. *Life* **2025**, *15*, 282. https://doi.org/10.3390/life15020282

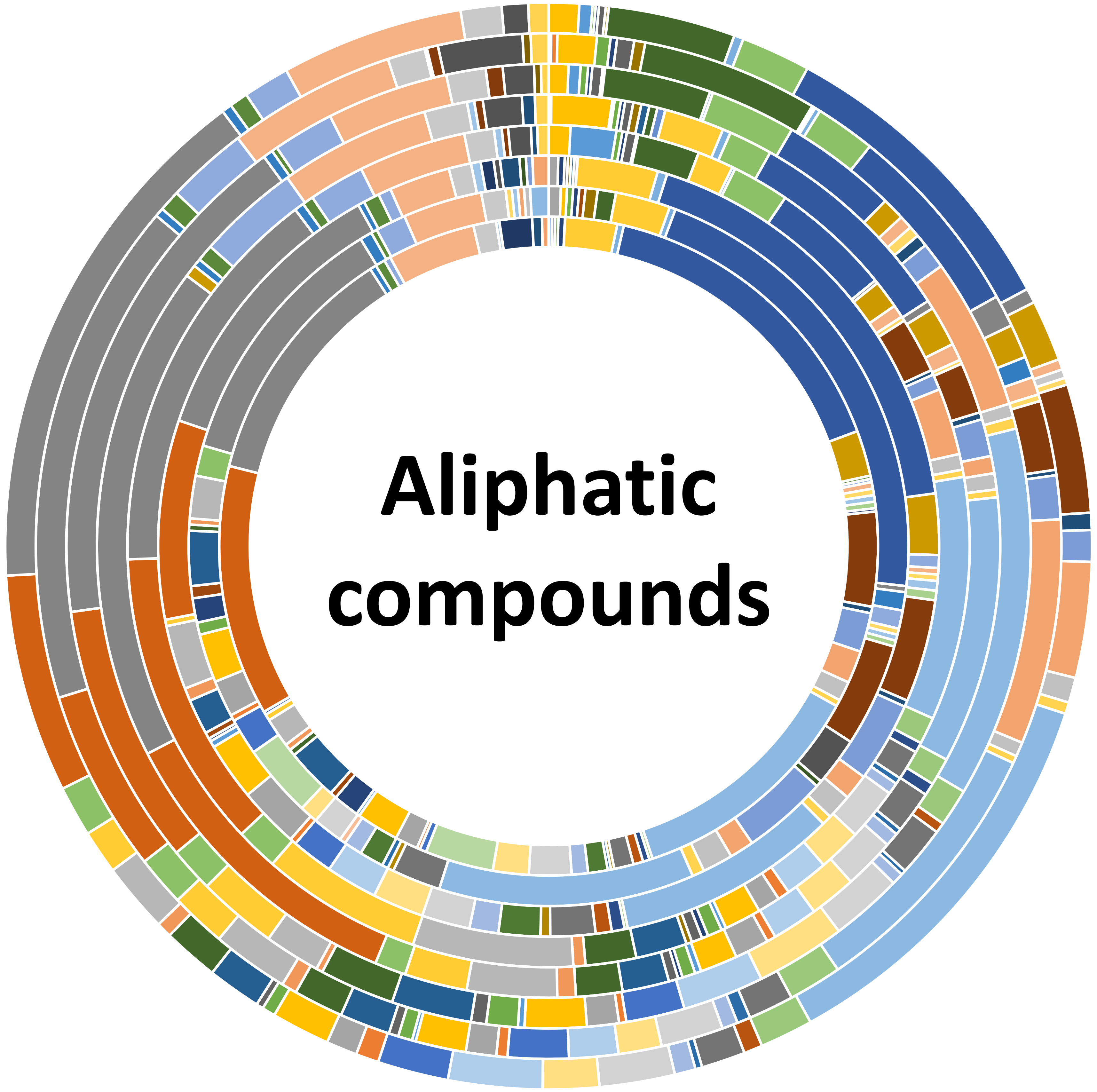
1. Introduction

Current global trends in health awareness and environmental stewardship are driving an increase in the demand for natural products, including those derived from medicinal and aromatic plants (MAPs). MAPs are preferred because they are considered natural, relatively safe and environmentally friendly [1], as well as for their role in traditional or folk medicine [2]. The therapeutic, cosmetic, nutraceutical and other benefits derived from plants are due to thousands of secondary plant metabolites that are produced from metabolic pathways that breakdown carbohydrates, lipids, nucleic acids and proteins (the primary metabolites). While primary metabolites ensure fundamental processes for plant survival such as growth, development and reproduction, secondary metabolites facilitate long-term survival by providing protection against disease and predation, attracting pollinators and allelopathy [3].

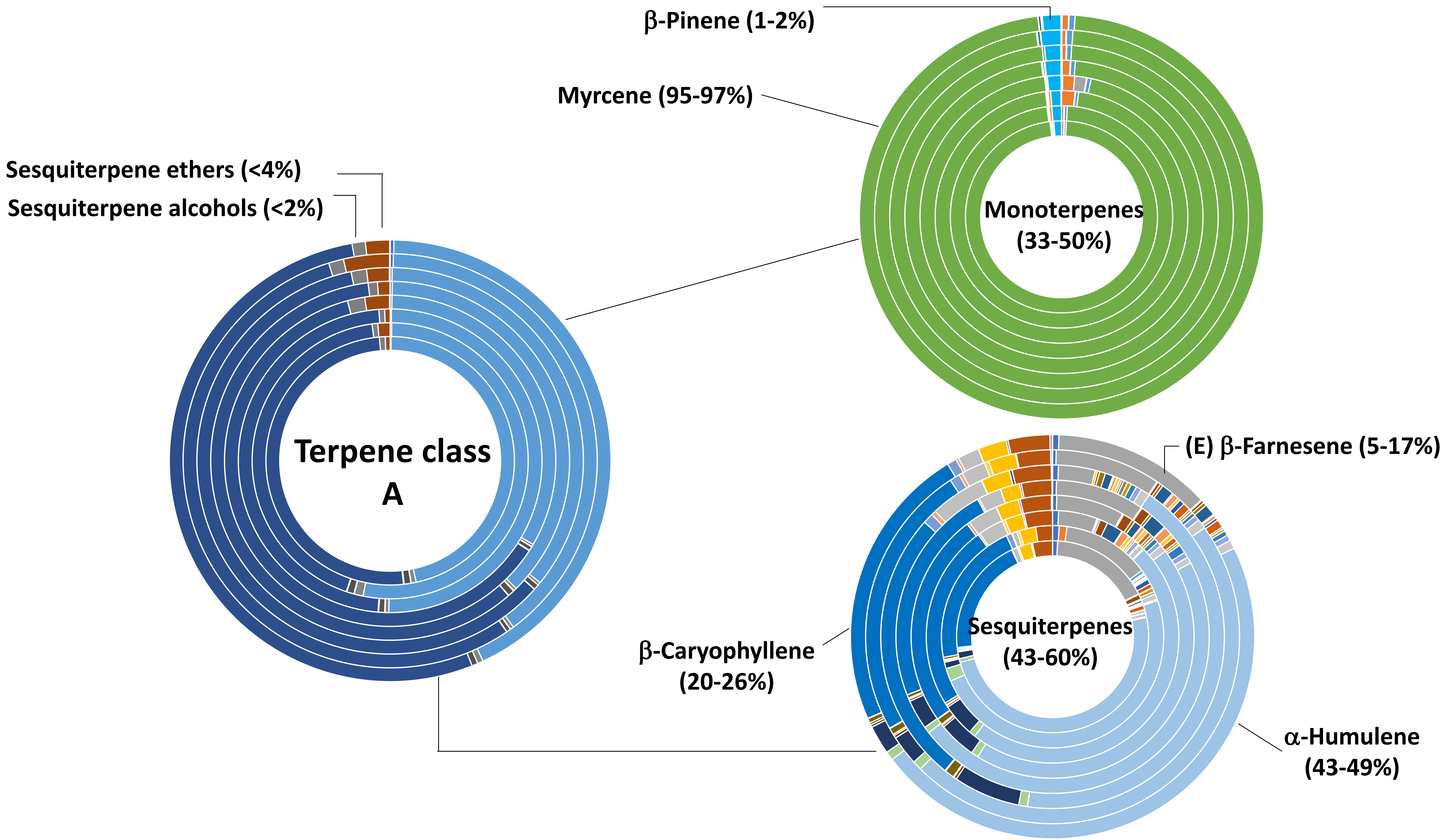
Compound Groups

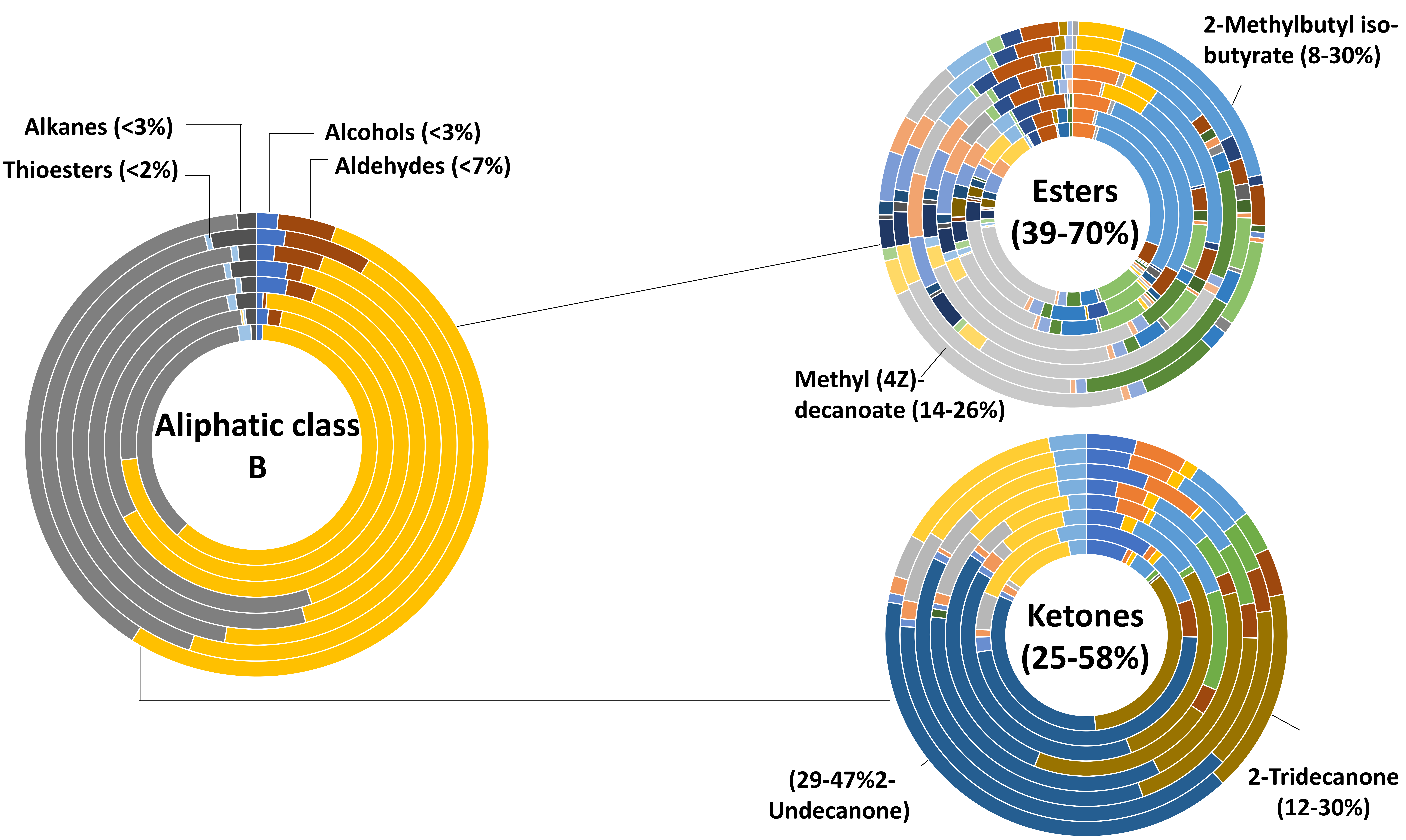


A



B


β-Pinene (1-2%)
Myrcene (95-97%)
Monoterpenes (33-50%)
Sesquiterpene ethers (<4%)
Sesquiterpene alcohols (<2%)
Terpene class
A
(E) β-Farnesene (5-17%)
β-Caryophyllene (20-26%)
Sesquiterpenes (43-60%)
α-Humulene (43-49%)


Alkanes (<3%)
Thioesters (<2%)
Alcohols (<3%)
Aldehydes (<7%)
Aliphatic class
B
Esters
(39-70%)
2-Methylbutyl iso-
butyrate (8-30%)
Methyl (4Z)-
decanoate (14-26%)
Ketones
(25-58%)
(29-47%2-
Undecanone)
2-Tridecanone
(12-30%)

NYSÉOS
AU CŒUR DE L'ARÔME

53 rue Claude François
34080 - MONTPELLIER
Tél : 04 67 72 06 41
Email : contact@nyseos.fr
www.nyseos.fr

Costumer : AnheuserBusch InbevNV/SA

ANALYTICAL REPORT : QUOTE N° 242167

Sample name:		South africa MD : 2024 BB : 2027 HOP PELLETS S PASSION Batch01		
METHOD LC-MS : VA-4THIOLS	**Unit**	**Results**	**LOQ**	**RSD**
3-sulfanylhexan-1-ol (1)	ng/g	3,85	0,10	6%
3-sulfanyl-4-methylpentan-1-ol	ng/g	0,62	0,10	6%
3-sulfanylhexan-1-ol Acetate (1)	ng/g	0,9	0,30	5%
4-methyl-4-sulfanylpentan-2-one (1)	ng/g	0,39	0,10	7%
METHOD LC-MS : VA-PRTHIOLS	**Unit**			
cystéine-3SH (1)	µg/g	0,72	0,007	3%
cysteinyl-glycine-3SH (1)	µg/g	1,22	0,006	5%
γ-glutamyl-cysteine-3SH (1)	µg/g	0,66	0,006	4%
gluthation-3SH (1)	µg/g	9,26	0,013	4%
cystéine-4SMP (1)	µg/g	0,015	0,002	5%
gluthation-4SMP (1)	µg/g	0,006	0,001	5%

Stable Isotopic Dilution Analysis : (1) labelled standards

nd : Not Detected

LOQ : Limit of Quantification

RSD : Relative standard deviation

Sample received on : 08 July 2024

Under responsability of : Stephane DELPECH, Laboratory Mana

NYSÉOS
AU CŒUR DE L'ARÔME

53 rue Claude François
34080 - MONTPELLIER
Tél : 04 67 72 06 41
Email : contact@nyseos.fr
www.nyseos.fr

Costumer : AnheuserBusch InbevNV/SA

ANALYTICAL REPORT : QUOTE N° 242167

Sample name:		Hops Hydrosol 2024 Season Lot47	Hop oil sample lot 40-44		
METHOD LC-MS : VA-4THIOLS	**Unit**	**Results**	**Results**	**LOQ**	**RSD**
3-sulfanylhexan-1-ol (1)	ng/L	44412	3139	1	6%
3-sulfanyl-4-methylpentan-1-ol	ng/L	nd	nd	1	6%
3-sulfanylhexan-1-ol Acetate (1)	ng/L	nd	609	3	5%
4-methyl-4-sulfanylpentan-2-one (1)	ng/L	65	308	1	7%
METHOD LC-MS : VA-PRTHIOLS	**Unit**				
cystéine-3SH (1)	µg/L	6,5		0,7	3%
cysteinyl-glycine-3SH (1)	µg/L	13,6		0,6	5%
γ-glutamyl-cysteine-3SH (1)	µg/L	nd		0,6	4%
gluthation-3SH (1)	µg/L	4,6		1,3	4%
cystéine-4SMP (1)	µg/L	nd		0,2	5%
gluthation-4SMP (1)	µg/L	nd		0,1	5%

Stable Isotopic Dilution Analysis : (1) labelled standards

nd : Not Detected

LOQ : Limit of Quantification

RSD : Relative standard deviation

Sample received on : 08 July 2024

Under responsability of : Stephane DELPECH, Laboratory Manager

Preserve Botanica Hop Oils and Hydrosols


Elk Mountain,
USA
Busch Farm,
Germany
Fern. Oro,
Argentina

Preserve BOTANICA
SPECIALIZED BOTANICAL PREPARATIONS

Waste is a resource

Sustainability has advantage

Science matters

Collaborate

African Solutions can go global

Preserve BOTANICA

SPECIALIZED BOTANICAL PREPARATIONS

THANK YOU!

SAB

To a Future With More Cheers

accelerator 100+