UDC 635.12:635.14]:577.1

BIOCHEMICAL CRITERIA OF BREWING EVALUATION OF AROMATIC HOP VARIETIES

https://doi.org/10.15673/fst.v18i3.3037

L. Protsenko[1], PhD, head of the department
N. Koshitska[1], PhD, the leading researcher of the department
S. Ryzhuk[1], Academician of the NAAS, Dr.Sc., professor, Head of the Institute
O. Svirchevska[1], Researcher
A. Bober[2], PhD, associate professor
S. Gunko[2], PhD, associate professor
L. Janse[3], Corresponding member of the NAAS, Doctor of Biological Sciences, Deputy Academician-Secretary of the Department of Agriculture, Land Reclamation and Mechanization of the NAAS
[1] Department of hop and beer biochemistry and biotechnology
Polissia Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine, Kyiv highway, 131, Zhytomyr, Ukraine,10007
[2] Department of Storage, Processing and Standardization of Plant Products after prof. B.V. Lesik
National University of Life and Environmental Sciences of Ukraine
Heroyiv Oborony str., 13, Kyiv, Ukraine, 03041
[3] National Academy of Agrarian Sciences of Ukraine, 9, Omelianovycha-Pavlenka Str., 01010 Kyiv, Ukraine

Correspondence:

A. Bober
E-mail: bober_1980@i.ua

Cite as Vancouver style citation

Protsenko L, Koshitska N, Ryzhuk S, Svirchevska O. Et al. Biochemical criteria of brewing evaluation of aromatic hop varieties. Food science and technology. 2024;18(4):35-46. https://doi.org/10.15673/fst.v18i3.3037

Цитування згідно ДСТУ 8302:2015

Biochemical criteria of brewing evaluation of aromatic hop varieties / Protsenko L. et al. // Food science and technology. 2024. Vol. 18, Issue 3. P. 35-46. https://doi.org/ 10.15673/fst.v18i3.3037

Abstract. With the expansion of the assortment of beer, brewers increasingly use different hop products of new varieties of hop, that makes it possible to obtain beer with certain profiles of taste and aroma. The comprehensive assessment of the quality of hop pellets Type 90 produced in Ukraine and European countries and that are most demand by Ukrainian beer producers were conducted. It made possible to form a database of biochemical characteristics of fine aromatic and aromatic varieties based on the absolute values of such indicators as the mass fraction of alpha-acids and beta-acids (with including their chemical composition), xanthohumol, essential oil and its components and the ratio of certain valuable hop compounds. The mass fraction of alpha-acids in hop pellets of fine aromatic varieties was ranges from 2.7% in the Hersbrucker variety to 5.3% in the Slavianka variety. A higher indicator of the content of alpha-acids was found in the pellets of the aromatic varieties Zagrava and Tradition with a range of variation of the indicator from 4.6 to 7.2% (average values are 5.9 and 6.0%, respectively). The content of beta-acids in the studied pellets ranges from 3.6% (Lublin) to 6.6% in the pellets of the Slavianka variety. The among the studied pellets in the composition of bitter substances the proportion of beta-acids is equal or exceeds the proportion of alpha-acids. As a result, they save a positive aromaticity ratio between the content of beta-acids and alpha-acids, that ranges from 0.99 (Lublin) to 1.84 (Hersbrucker). In the samples of hop pellets that was studied there is significant variability in the essential oil content with average values from 0.49 (Klone 18) to 1.64 ml/100 g in Zagrava hop pellets. The general components of essential oil of hops are hydrocarbons that are represented by monoterpenoid - myrcene and sesquiterpenoids: caryophyllene, humulene and farnesene, that collectively set up from 66.6% to 78.8% of their total amount. Biochemical criteria for brewery assessment of hop varieties of the aromatic type have been determined and scientifically substantiated. The main ones are the content and composition of bitter substances, in particular: alpha-acids and beta-acids with an indicator value in the range of 4–9%; the ratio between the number of beta- and alpha-acids is about 1; the mass fraction of cohumulone in the composition of alpha-acids is up to 28%; the amount of essential oil per 1 g of alpha-acids is within 0.20–0.25 ml in the presence of a significant amount of sesquiterpenoids. The amount of farnesene in the composition of the essential oil was within 10–20%, the content of prenylated flavonoids, in particular xanthohumol, was at least 0.4%. A new hop variety Perlyna with characteristics that requirements the specified criteria is presented. Expanding the assortment of hop products due to the formation of highly productive hop plantations of new varieties with defined characteristics is an important prerequisite for ensuring a sufficient level of competitiveness of Ukrainian hop products on the world market.

Keywords: hop pellets type 90, hop varieties, biochemical criteria, brewery assessment, bitter substances, hop essential oil.

Introduction. Formulation of the problem

With the expansion of the range of beer, especially with the development of the new trend of Craft beer and the creation of original beer styles, brewers are increasingly using a different new hop products made from new varieties of hop, that makes it possible to obtain beer with certain profiles of taste and aroma, since modern hop varieties have a wide range of the bitter substances and other valuable compounds that are necessary for this purpose.

For brewers, hops are an irreplaceable raw material that determines the character of beer [1-4]. For many centuries, hops, as the main component in brewing beer, give it not only piquant bitterness, but also a unique aroma [5-7]. This is due to the variety of bitter substances, essential oils and aromatic compounds that contained in the cones of different varieties of hops [3,7,8].

But far from everywhere, even in countries with a temperate climate that are leaders in hop production: Germany, the Czech Republic, the North America and China [8], there are favorable natural and climatic conditions for hop cultivation, similar to Ukraine [9]. The development of hop production in Ukraine corresponds to the preservation of centuries-old national brewing traditions with an emphasis on valuable varieties of hop with a fine aroma [10-12]. Thanks to this, Ukraine has the opportunity to develop the sectoral complex of hop, grow the necessary amount of hop raw material and process it into appropriate hop products to suppling its own brewing needs and build export potential [13-15]. An important background for ensuring a sufficient level of competitiveness of domestic hop production is the expansion of its assortment due to the formation of highly productive hop plantations of new varieties [16].

Analysis of recent research and publications

The most important hop compounds for brewing are bitter substances. Their importance and value explaining in the fact that these substances are not found in other plants. They are mainly represented by alpha- and beta-acids. In addition to giving beer a characteristic bitter taste, bitter substances in a complex with other hop compounds contribute to the clarification of beer, effect on the color and foam formation, and also increase the biological and colloidal stability during storage of the amber drink [2,7].

In addition to bitterness, hops give beer special taste notes, unique spiciness and a specific hop aroma [1,4]. This is explained to the assortment of aromatic substances contained in the essential oil of hops and synthesized together with bitter substances in the lupulin glands during the formation and ripening of hop cones [8,17]. The diverse composition of hop essential oil gives beer individual taste qualities and aromatic properties, including citrus, floral, fruity notes, spicy, woody, herbal aromas, depending on the hop variety [3,7,18].

Since bitter substances and essential oil are the main factors in the taste and aroma of beer, their amount and composition in different types of hops contain valuable information for brewers [1,3], and have main for the improvement of brewing techniques, especially in the context of the growing popularity of the Craft beer trend [19,20]. The brewers are increasingly using various hop varieties with a qualitatively different composition of bitter substances and essential oils with aim to create special aroma and taste profiles in beer [11,19-22]. Today, breeding programs of leading countries in the field of hops: the Czech Republic, Germany, the USA, China, Poland and others are aimed at creating hop varieties with unique characteristics [5,8,12,23].

Beside, biologically active compounds of hop cones are known for their antioxidant, anti-inflammatory, antitumor properties [24-27], that should attract the attention of the pharmaceutical industry. Also, the essential oils and resins of hops have sedative and other neuropharmacological properties, as well as demonstrate antibacterial and antifungal activity [28,29], offering a natural alternative to synthetic insecticides [30-32].

The analysis of data from the world scientific literature and the results of our own researches indicate a wide range and high levels of biological activity of hop compounds and substantiate the prospects of using hops and its processing products not only in brewing, but also in other areas of human activity.

That is why the evaluation of hop varieties is carried out comprehensively, covering various aspects, including agrotechnological and economic characteristics during their optimal cultivation and processing and also chemical and technological characteristics [5,32-35]. The stability of the technological and biochemical quantitative and qualitative characteristics of the variety remains an actual problem today for the Brewers Association of America [23,36], European brewers [3-5,8,37] and Ukrainian beer producers [11,12], as this knowledge makes it possible to establish suitability of the variety for successful use in brewing. And also selecting varieties of hops to obtain beer with high-quality bitterness and a sought-after aroma. The investigation of the composition of bitter substances, essential oil and other biologically active compounds of hops and the determination of criteria for evaluating aromatic and bitter varieties of hops is important for the successful development of brewing of various directions and other areas of human activity [1,3].

The purpose of the study was to determine and justify the biochemical criteria for the brewing

assessment of hop varieties of the aromatic type and create a new hop variety with defined characteristics.

To achieve the goal, the following **tasks** were formulated:

- to determine the physico-chemical and biochemical indicators of the quality of hop pellets type 90 of fine-aromatic and aromatic varieties of Ukrainian and European production, that have the most demand in the technologies of Ukrainian beer producers;

- to create a database of biochemical indicators of the quality of aromatic hop varieties, the hop production from them is in the greatest demand among Ukrainian brewers;

- on the basis of theoretical and experimental studies, analysis of databases of biochemical indicators of studied varieties, to determine and justify biochemical criteria for brewery assessment of aromatic hop varieties.

Research materials and methods

The research was conducted in 2017–2023 in the accredited laboratory of hop and beer biochemistry and biotechnology of the Polyssia Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine, the production conditions of hop granulation at LLC "Hop of Ukraine", PE "Halchyn-agro" and breweries of Ukraine.

Biochemical indicators of the quality of hop pellets type 90 of fine-aromatic and aromatic varieties of Ukrainian and foreign production that are greatest demand among Ukrainian brewers were studied:

- Pellets of hops of fine-aromatic varieties of Ukrainian selection with a delicate aroma: Klon 18 and Zlato Polissya that are variation of the Zhatec type of hops with an alpha-acid content range of 3.0–5.5% and the Slavyanka variety with an alpha-acid content of 4.5–7.5%.
- Pellets of foreign selection varieties of hops of the Zatec type with a delicate aroma: Zhatetsky (Czech Republic), Thettnanger, Shpalt Select, (Germany), Lublin (Poland) with alpha-acid content from 2.5 to 6.5%.
- Pellets of hops of fine aromatic varieties of foreign selection with farnesene-free type of essential oil: Hersbrucker, Sapphire (Germany) that characterized by a range of alpha-acid content from 1.5 to 4.5%;
- Pellets of hops of aromatic varieties of Ukrainian selection with a characteristic hop aroma: Nationalny and Zagrava that have alpha-acid content in the range of 5.0–9.0%.
- Pellets of hops of an aromatic variety of foreign selection with a characteristic hop aroma: Halertau Tradition (Germany) with a range of alpha-acid content from 4.0 to 7.0%.
- Pellets of hops of a new, fine aromatic variety of Ukrainian selection with a delicate aroma Perlyna that have alpha-acid content in the range of 4.5–9.0%.

The samples were taken from consignments of pellets of the respective varieties. The weight of the average sample for identification and biochemical studies was at least 1 kg of hop pellets. 7–10 samples from consignments of pellet of each variety were studied.

Modern physico-chemical methods of analysis of bitter substances, essential oil of hops and hop products were used in the research, in particular: high-performance liquid chromatography, capillary gas chromatography, spectrophotometry, other control methods harmonized with the methods of European Brewing Convention, as well as mathematical and statistical methods using dispersion and correlation-regression analysis to assess the reliability of the obtained research results.

Methods of researching the quantity and qualitative composition of bitter substances of hop pellet. The quantity of alpha-acids is a conductometric indicator of bitterness, determined according to the international method Analytika EVS 7.5 [33,38]. This method is based on the conductometric titration of the diethyl ether extract of bitter substances of hop by solution of lead acetic acid with calculation of the mass fraction of alpha-acids. The content and composition of alpha-, beta-acids and xanthohumol were determined by the method of high-performance liquid chromatography according to the international method of EVS 7.7. [33,38]. Bitter substances of hop: alpha- and beta-acids and their components, in particular, cohumulone, colupulone and xanthohumol, were extracted from hop pellets by an organic solvent - methanol. The ratio between the mass of hop pellets and the extractant was 1:10. The amount of alpha- and beta-acids and the content of cohumulone, copululone and xanthohumol were determined by the method of high-performance liquid chromatography. Chromatography was carried out with using an Ultimate 3000 liquid chromatograph with a UV detector at temperature of 35 ºC. A column measuring with 100 x 2.1 mm was used that was filled by Pinacle DV C18 sorbent 3 μm. A solution of methanol, water and acetonitrile in a ratio of 38:24:38 was used as the mobile phase. The content of xanthohumol determine with used the xanthohumol standard that have content of this compound of 99.8%, for the components of bitter substances: alpha- and beta-acids - the international standard ISF-3 [38].

Methods of research on the quantity and qualitative composition of essential oil of hops. The content of essential oil was determined according to the international method Analytika EVS 7.10 [39] that is based on the determination of the content of essential oil in cm^3 in terms of 100 g of air-dry matter with obtaining essential oil by hydrodistillation followed by decantation and collection it is in a special catcher.

The chemical composition of the essential oil was

analyzed by gas chromatography following the official method in Analytica-EBC 7.12 [40]. Four selected components (myrcene, caryophyllene, farnesene, humulene) were identified and quantified with using a Krystal-2000M capillary gas chromatograph equipped by flame ionization detector. The essential oil extracted from the hop pellets was separated into separate compounds by gas chromatography on 50–60 m columns (Restek Stabilwax® manufactured by the USA) with using 20–30 cm^3 of chromatographically inert nitrogen carrier gas. The temperature program was as follows: 60°C (exposure for 1 min), 60–190°C (4°C/min), 190–220°C exposure in isothermal regime for 40 min). The injector temperature was 220°C, the injection volume was 0.3–0.4 μl, and the detector temperature was 250°C. The results were expressed as a relative % of particular compound in the essential oil.

Results of the research and their discussion

With aim for determine and substantiate the biochemical criteria for the brewing evaluation of aromatic hop varieties, we have researched the chemical and technological indicators of the quality of aromatic hop varieties of Ukrainian and European selection, the hop products from them was the most demand during the years 2017–2023 in the technologies of Ukrainian beer producers, and created a database of biochemical indicators of the studied varieties. Type 90 hop pellets were studied, the chemical composition of them practically does not differ from hop cones [41].

The most important compounds of hop and its processing products for brewing are bitter substances. The most valuable among bitter substances are alpha-acids that are the main price-forming factor in the evaluation of hop and hop products [13,42]. At wort process hopped by hop, alpha-acids are isomerized into iso-alpha-acids that are the main compounds of beer bitterness, giving it a characteristic bitter taste [12,43-45]. As a result of isomerization of these compounds, almost 90% of beer bitterness forming [44,46]. The values of the minimum, average and maximum content of alpha-acids in hop pellets of the studied varieties are given on the Fig. 1.

As a results of analysis of the data that presented on the Fig. 1, it can be seen that the minimum amount of alpha-acids over the years of researching was determined in the pallets of the Hersbrucker variety, that was 1.9% (average index 2.7%). A higher index of alpha-acids content, with average values of the index from 3.4% to 3.8% among the fine-aromatic varieties, was determined in the hop pellets of the following varieties: Clone 18, Zhatetsky, Thettnanger and Sapphire. According to the passport data of these varieties [47–50], the content of alpha-acids is in the range of 2.5–4.5%. Almost the same quantity with a difference between the limits of the evaluated characteristic of 3.1–5.5% was also determined in the pallets of the Zlato Polissya and Lublin varieties with average values of the indicator of 4.1–4.3%, respectively.

Hop pellets of the Shpalt Select, Sloavianka and National varieties had a wider range of alpha-acids content from 3.9 in the Shpalt Select to 6.8 in the National. However, the average indicator of the evaluated feature was at the level of 5.0–5.3%.

The highest index of alpha-acids content among aromatic varieties was determined in hop pellets of the Zagrava variety with a range of variation of the index from 4.8 to 7.2%, the average value of it was 5.9%. Almost the same average value of the indicator of the mass fraction of alpha-acids of 6.0% was determined in the cones of the Halertau Tradition variety, with fluctuations of the indicator from 4.6 to 6.9%.

Equally important compounds for brewing are beta-acids, which, together with alpha-acids, determine the bitterness of hop and beer. Beta-acids do not taste bitter, but at wort is hopped, compounds are formed that have a pleasant, soft bitterness [44]. Beta-acids have a high antiseptic effect, antibacterial and antifungal activity [2,29,32], which helps to increase the stability of beer during its storage [32]. The obtained data on the minimum, average and maximum content of beta-acids in hop pellets of the studied varieties are presented on the Fig. 2.

The minimum amount of beta-acids over the years of researching, according the data on the Fig. 2, was determined in pellets of the Lublin variety with the range of the content of this compound from 2.5 to 4.1%, with an average of 3.6%. It should be noted that all pellets of Zhatec type varieties had approximately the same content of beta-acids, with average values of the indicator from 3.6 to 5.3%, respectively. The content of beta-acids in the pellets of the Hersbrucker and Sapphire varieties were 2.6 to 6.7%, with average values of the indicator of 4.6 and 5.4%, respectively. The highest amount of beta-acids among the fine aromatic varieties was determined in the hop pellets of Slavyanka variety with a variation range of the indicator from 4.8 to 7.7%, the average value of the indicator was 6.6%. Almost the same number of them with a difference between the limits of the evaluated characteristic of 4.9–6.8% was also determined in the pellets of the Zagrava variety, with an average value of the indicator of 6.1%.

On the basis of the obtained data of biochemical investigations of the amount and composition of bitter substances in the pellets of hop of fine aromatic and aromatic varieties, we found that the pellets made from the varieties of Ukrainian selection Zagrava and Slavianka have significantly higher indicators of the content of beta-acids compared to the pellets of the remainder of the studied foreign varieties.

Beer with a characteristic bitter taste and a sought-after aroma can be obtained only under the condition of using hop and its processing products of

individual varieties that connected with the peculiarities of their biochemical composition, and first of all, with the quantity and qualitative composition of bitter substances, polyphenols and essential oil, moreover, the optimal ratio of individual components of these compounds has a positive effect on the taste and aromatic properties of beer [11]. Biochemical indicators of the content and composition of bitter substances in hop pellets of the aromatic type of Ukrainian and European production for the years 2017–2023 are presented in the Table 1.

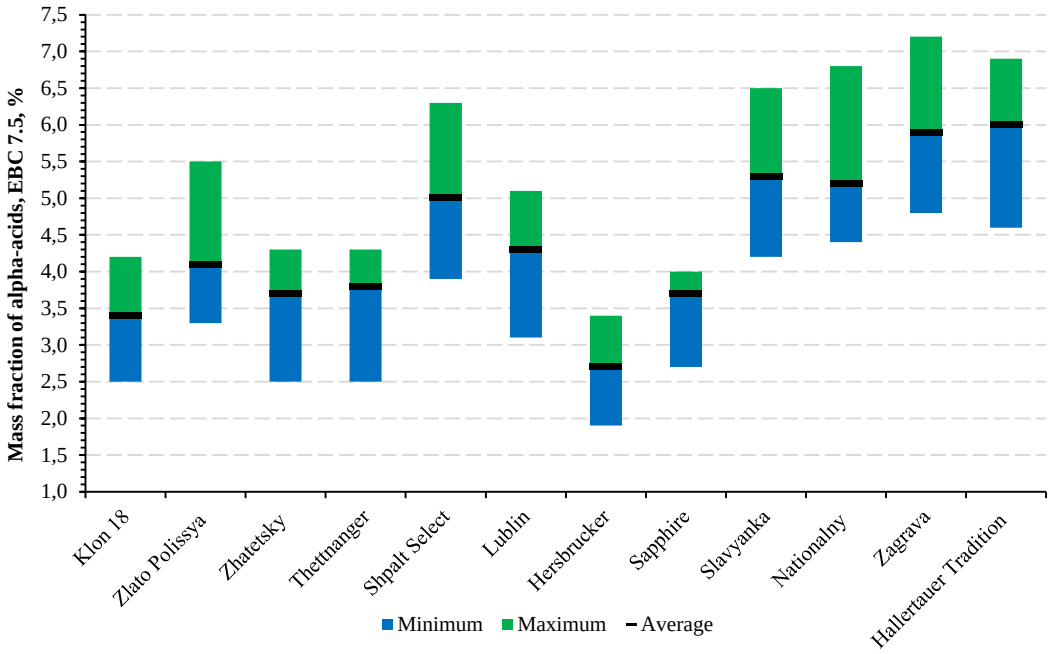

Fig. 1 – Content of alpha-acids in hop pellets of the studied varieties (average data for 2017–2023 with n=3, P≥0.95)

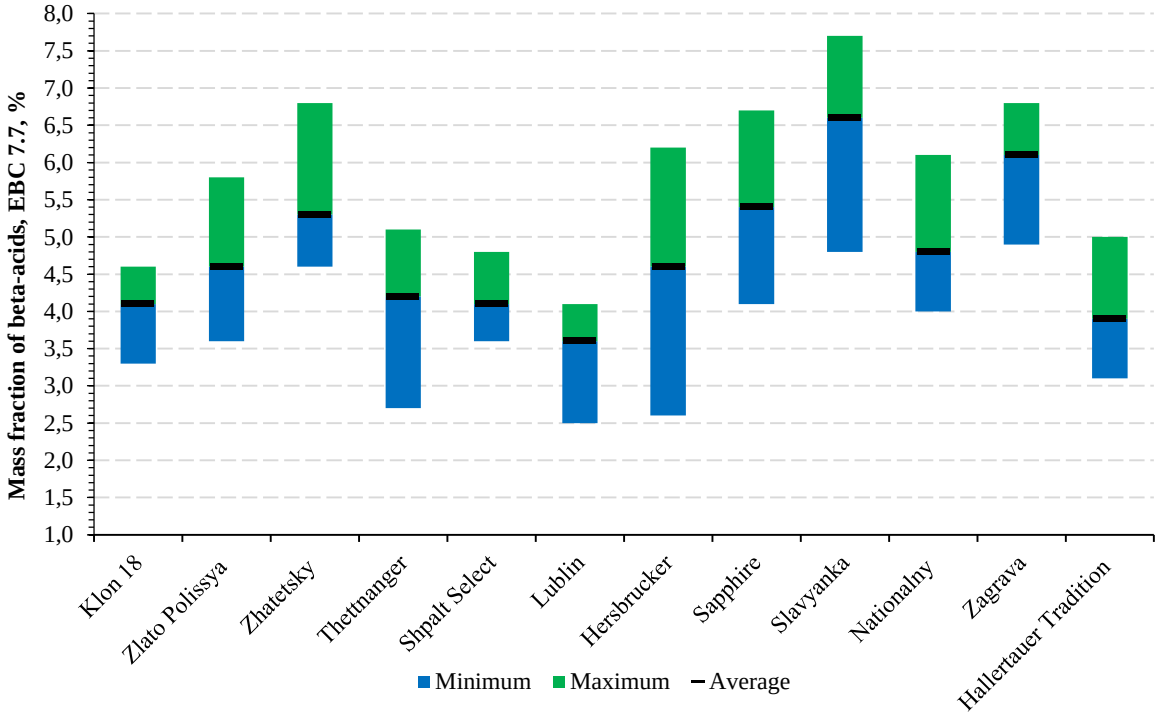

Fig. 2 – Content of beta-acids in hop pellets of the studied varieties (average data for 2017–2023 with n=3, P≥0.95)

Table 1 – Content and composition of bitter substances in hop pellets of studied varieties for 2017–2023 (average at n=3, P≥0.95±SD)

No.	Pellets of the hop variety	Mass fraction, %		β/α, EBC 7.7	Cohumulone in the composition of α-acids, %	Colupulone in the composition of β-acids, %	Xanthohu-mol, %
		alpha-acid, EBC 7.5	beta-acid, EBC 7.7				
Pellets of hop varieties of the fine aromatic type							
1	Klon 18	3.4±0.74*	4.1±0.42	1.31±0.67	25.1±±2.01	45.3±1.9	0.24±0.051
2	Zlato Polissya	4.1±0.32	4.6±0.24	1.21±0.57	23.2±1.75	43.2±1.81	0.38±0.033
3	Zhatetsky	3.7±0.53	5.3±0.47	1.28±0.45	24.7±1.86	41.8±1.38	0.39±0.034
4	Thettnanger	3.8±0.42	4.2±0.37	1.19±0.31	23.7±0.98	43.8±1.34	0.26±0.031
5	Shpalt Select	5.0±0.74	4.1 ±0.43	1.01±0.29	23.9±1.17	43.1±2.06	0.23±0.043
6	Lublin	4.3±0.62	3.6±0.58	0.99±0.26	26.8±0.86	46.1±0.63	0.37±0.028
7	Hersbrucker	2.7±0.41	4.6±0.89	1.84±0.87	21.3±1.98	37.6±2.22	0.19±0.024
8	Sapphire	3.7±0.45	5.4±0.93	1.69±0.20	15.1±1.62	44.1±1.69	0.38±0.037
9	Slavyanka	5.3±0.81	6.6±1.11	1.29±0.44	23.5±1.26	42.0±1.38	0.41±0.042
10	Nationalny	5.2±0.82	4.8±0.88	1.09±0.43	21.4±1.15	40.1±1.49	0.37±0.038
Hop pellets of aromatic types							
11	Zagrava	5.9±1.22	6.1±0.95	1.11±0.38	23.2±1.87	44.4±2.15	0.43±0.051
12	Hallertauer Tradition	6.0±0.87	3.9±0.78	0.87±0.11	28.1±1.42	47.5±2.52	0.33±0.046

Note: *average values of indicator X for 2017–2023 years ±SD

A characteristic feature of the studied varieties is the positive aromaticity coefficient between the content of beta- and alpha-acids that is greater than or close to 1. This is one of the criteria for assessing the brewing quality of hop and pellets. Hop pellets of the varieties Klon 18, Zlato Polissya, Zhatetskyi, Thettnanger and Slavianka have a significant advantage in the composition of bitter substances of the portion of the beta-acids over the portion of alpha-acids. The aromaticity coefficient between the content of beta- and alpha-acids was in the range of 1.19–1.29. An even higher index of aromaticity, from 1.69 to 1.84, was determined in the pellets of varieties that have a farnesene-free type of essential oil Sapphire and Hersbrucker. For the another pellet samples of this indicator was in the range from 0.87 to 1.11.

The great importance in the formation of the taste of the drink and the quality of the bitterness of beer is not only the amount of bitter substances in hop, but also the qualitative composition of homologues that are part of the original alpha- and beta-acids, and, first of all, this concerns the content of cohumulone in alpha-acids and colupulone as part of beta-acids.

Cohumulone is converted into an isomer better than other components of alpha-acids. But this fraction is attributed a negative role in the formation of beer bitterness. Scientists noted that brewing of hop varieties with a predominant content of cohumulone, the beer mainly contains iso-cohumulone, and the quality of bitterness according of data [51,52] and results others investigators been worsening. An increase in the proportion of cohumulone in hop gives beer residual bitterness and a rough shade of bitter taste. And vice versa, then the less cohumulone is contained in the composition of alpha-acids, than the better the quality of the bitterness of the drink. According to scientists and specialist brewers from Germany, the Czech Republic, Slovenia, and the United States of America [51,52], the mass fraction of cohumulone in the composition of alpha-acids in fine aromatic varieties should not exceed 30%. Although according to [17], this question is debatable and there is no clear answer.

The smallest portion of cohumulone in the composition of alpha-acids over the years of research was determined in the pellets of the Sapphire variety with a range of variation of the indicator from 13.8 to 17.0%, with an average value of the indicator is 5.1%. In the another varieties, the average value of the portion of cohumulone ranged from 21.3% and 21.4% in the pellets of the Hersbrucker and National varieties to 28.1% in the Tradition variety. In the pellets of this variety, the largest portion of colupulone in the composition of beta-acids was determined – 47.5%. These indicators are one of the characteristic features of the breeding variety. We also noted that in all hop pellets of Ukrainian production of fine aromatic and aromatic varieties, the content of cohumulone is in the range of 21.4–25.1%, colupulone – from 40.1 to 45.3%, respectively, that is, this once again confirms that Ukrainian varieties have a high-quality composition of bitter substances.

In addition to bitterness, hop also gives beer a specific aroma, unique spiciness and a fine hop flavor [1,4]. This is due to the diversity of the composition of essential oil and aromatic substances contained in hop cones that give beer a unique hop

aroma [8,17]. Although the portion of these substances in the chemical composition of hop cones is only 0.1–4.2% [5,11,53], they are decisive in the aroma of both hop and beer.

Essential oil, as well as bitter substances, are synthesized and accumulated during the formation and ripening of cones and are concentrated mainly in the lupulin glands of hop cones. Moreover, the main amount of essential oil accumulates at the end of the synthesis of bitter substances. In the process of formation and ripening of hop cones, the amount of essential oil increases, reaching the maximum level in the stage of physiological ripeness. In Fig. 3 the values of the minimum, average and maximum content of essential oil in hop pellets of the studied varieties were given.

In the hop pellets of the studied samples that have main importance for brewing, there is a significant variability in the content of essential oil, with average values from 0.49 (Clone 18) to 1.64 ml/100 g of hop pellets Zagrava.

Among the fine aromatic hop varieties of the Zhatec type, over the years of researching, the minimum amount of oil was determined in the cones of the Klon 18 variety that was 0.40–0.64 ml/100 g of dry hops, on average 0.49 ml/100 g. Almost the same the amount with a difference between the limits of the evaluated characteristic of 0.38–0.80 ml/100 g of dry hop was also determined in hop pellets of the Thettnanger, Zhatetsky, Lublin, Zlato Polissya, Hersbrucker and Shpalt Select varieties with average indicators of 0.56–0. 66 ml/100 g of dry hop. According to the passport data of these varieties [47-50], the oil content is in the range of 0.4–1.4 ml/100 g of dry hop. In the cones of the finely aromatic Slavyanka hop was determined much more oil (1.46 ml/100 g).

Among the aromatic varieties (Zagrava and Tradition), the maximum amount of essential oil was contained in the hop of the Zagrava variety that had 2.3 ml/100 g, the average value for the studied years was 1.64 ml/100 g of dry hop. Table 2 provides detail conclusions about total essential oil accumulation and variation in its composition during 2017–2023.

Most of the components of essential oil of hop are hydrocarbons and they are represented by monoterpenoid - myrcene and sesquiterpenoids - caryophyllene, humulene and farnesene with collectively constituting from 66.6% to 78.8% of their total amount.

Hop pellets in the composition of essential oil contain myrcene from 22.1% in pellets of the Thettnanger variety to 33.1% in the Zagrava variety. Caryophyllene in the studied varieties is in the range from 8.1 to 12.6% that is typical for European varieties. All studied samples of hop pellets in the composition of essential oil have a high content of humulene from 16.4% (Slavyanka) to 37.1% (Tradition) that presence of which refers them to varieties with a fine aroma. All varieties of the Zhatec type and the aromatic Zagrava variety have a high content of farnesene in the composition of the essential oil, from 15.4 to 19.9%. However, the largest amount of farnesene in the composition of the essential oil during 2017-2023 was the pellets of the Zhatetsky and National varieties with the corresponding average values of 19.7 and 19.9%. The hop pellets of the three investigated varieties (Sapphire, Hersbrucker and Tradition) had less than 1% of farnesene in the composition of the essential oil.

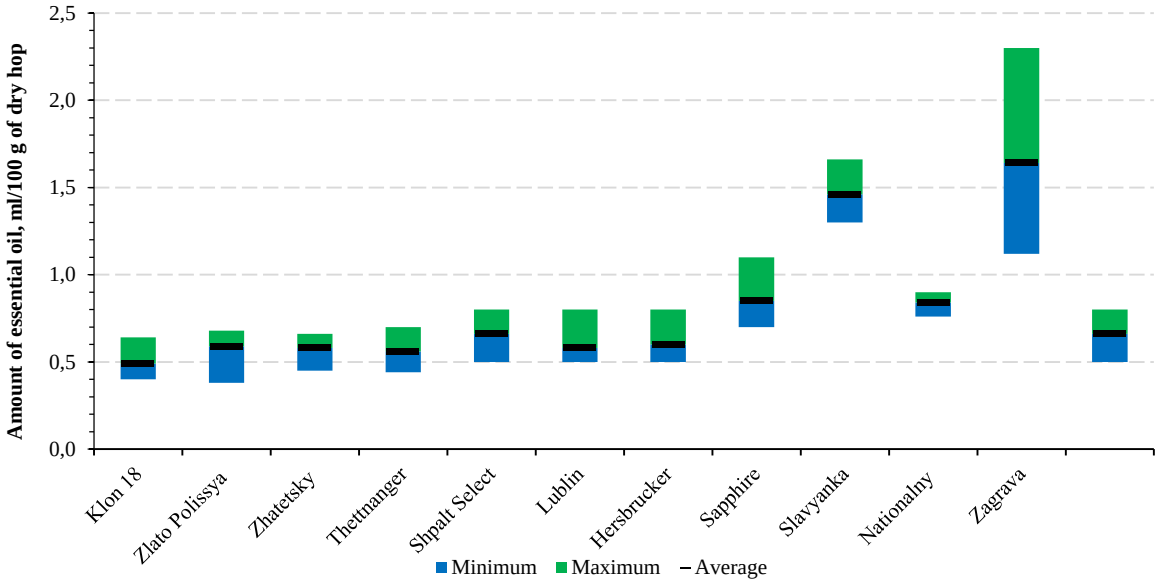

Fig. 3. The content of the total amount of essential oil in the hop pellets of the researched varieties (average data for 2017–2023 with n=3, P≥0.95)

Table 2 – The amount of essential oil and its qualitative composition in pellets of domestic hop varieties for 2017–2023 (average at n=3, P≥0.95±SD)

Hop varieties	Amount of essential oil, ml/100 g of dry hop	% to total content				Amount of essential oil, ml/100 g of dry hop to 1 g of alpha acids
		myrcene	caryophyllene	humulene	farnesene	
Fine aromatic and aromatic type of hops						
Klon 18	0.49*±0.042	26.8±3.8	8.7±1.37	24.5±3.9	17.4±2.2	0.14±0.033
Zlato Polissya	0.59±0.033	25.9±3.9	9.3±0.92	26.9±4.1	16.7±1.7	0.14±0.021
Zhatetsky	0.58±0.032	28.6±3.6	8.1±1.11	20.9±2.6	19.7±2.4	0.15±0.027
Thettnanger	0.56±0.014	22.1±3.9	9.2±1.22	26.3±4.9	18.5±1.8	0.15±0.022
Shpalt Select	0.66±0.026	23.4±4.1	8.9±1.38	18.7±2.8	18.8±2.2	0.13±0.031
Lublin	0.59±0.018	26.7±4.7	10.1±1.03	28.3±5.8	11.3±0.9	0.14±0.018
Hersbrucker	0.60±0.027	25.9±4.3	11.8±1.27	27.9±3.9	< 1	0.22±0.037
Sapphire	0.85±0.030	27.3±4.6	12.2±1.67	25.5±2.9	< 1	0.23±0.051
Slavyanka	1.46±0.045	32.9±5.3	8.8±1.32	16.4±4.7	17.5±2.2	0.28±0.057
Nationalny	0.84±0.041	29.2±4.2	9.5±1.11	17.3±2.9	19.9±2.3	0.16±0.033
Zagrava	1.64±0.075	33.1±6.8	8.1±1.79	18.7±4.1	15.4±2.2	0.28±0.062
Hallertauer Tradition	0.66±0.045	27.1±4.3	12.6±1.27	37.1±5.9	< 1	0.11±0.029

Note: * average values of indicator X for 2017–2023 ± SD

The results of researching proved that the chemical composition of the essential oil of the investigated samples of hop pellets of 12 varieties of Ukrainian and European breeding is a varietal feature and can be one of the biochemical criteria for identification of breeding varieties of hop. It was confirmed that the content and composition of the essential oil in the studied hop pellets correspond to the passport data of the studied varieties [47-50].

The results of our research on the quantitative content and qualitative composition of bitter substances and essential oil in hop pellets of fine aromatic and aromatic varieties of foreign selection are corresponding with the results of other researchers who characterize the hop varieties that we studied [5,48-50].

On the basis of theoretical and experimental studies, analysis of databases of biochemical indicators of hop varieties, the hop products of that the most demand in the technologies of Ukrainian beer producers, biochemical criteria for brewery assessment of hop varieties of the aromatic type have been determined.

The minimum criterion for the content of alpha acids was the maximum value of this compound in the hop pellets of the Zhatetsky variety, that is the standard for fine aromatic varieties and have level is 4.3%. The maximum value of the alpha-acid content in the group of aromatic varieties was established maximum level of the content of alpha-acids that must be do not less than 7.5%. The minimum and maximum values of the mass fraction of beta-acids were taken as the minimum content of this compound in the pellets of the Zhatetsky variety – 4.6%, and the maximum content was up to 7.7% (Slavianka variety).

According to scientists and specialist brewers [51,52], the mass fraction of cohumulone in the composition of alpha acids should not exceed 30%, that is confirmed by the results of our research, therefore, the maximum value of this indicator was established on the level 28%, that was determined in pellets of the Tradition variety. The ratio of beta-acids to alpha-acids is taken to be close to 1. The amount of essential oil based on 1 g of alpha-acids (data in Table 2) is within 0.20–0.25 ml in the presence of a significant amount of sesquiterpenoids. The amount of farnesene in the essential oil is within 10–20%.

On the basis of the developed and scientifically based biochemical criteria for the brewing evaluation of hop varieties and hop products, a new type of hop of the fine aromatic Perlyna type with optimal biochemical and technological characteristics for brewing was created.

The Perlyna variety was created by the method of individual selection from a population of regenerating plants of in vitro callus strains of the Slavianka variety. Received patent No. 230201 for the hop variety of ordinary Pearl. (Application: No. 22072001, priority date: 15.07.2022, date of state registration of intellectual property rights to plant variety: 09.03.2023.)

The Perlyna variety represents an elite group of fine aromatic and aromatic hop varieties. It is characterized by a unique composition of bitter substances and farnesene type essential oil. It has an optimal ratio (near 1) between the amount of beta-acids and alpha-acids (Table 3) and the mass fraction of cohumulone in the composition of alpha-acids is up to 28%, that observed in the best varieties of the world collection.

The aroma of Perlyna hop is formed from the balanced composition of its essential oil (Table 4), the amount of which was determined up to 2.3 ml per 100 g of dry hop.

Table 3 – Characteristics of bitter substances of hop pellets of the Perlyna variety for 2019–2023 (average at n=3, P≥0.95)

The type of hop is fine aromatic		
Bitter substances:		
	Total amount of bitter substances, %	22.0–29.0
	Content of alpha-acids, %	4.5–9.2
	Content of beta-acids, %	4.0–9.0
	The ratio between the amount of beta- and alpha-acids	0.9–1.2
	The mass fraction of cohumulone in the composition of alpha-acids, %	21.3–27.2
	The mass fraction of colupulone in the composition of beta-acids, %	39.2–48.4
	Amount of essential oil ml/100 g of dry hop to 1 g of alpha-acids	0.20–0.28

Table 4 – Biochemical and technological indicators of the essential oil of hop pellets of the Perlyna variety for 2019–2023 (average for n=3, P≥0.95)

The total amount of essential oil, ml per 100 g of dry hop	1.1–2.3
Myrzen, %	28.3–39.7
Caryophyllene, %	3.5–8.7
Humulene, %	10.3–16.0
Farnesene, %	12.7–17.5
Polyphenols:	
Total polyphenols, %	4.0–5.5
Xanthohumol, %	0.3–0.6
Brewery rating (point)	24.5–25.0

Hop of the Perlyna variety have up to 17% farnesene in the composition of essential oil, the ratio of humulene and caryophyllene is more than 3 that characterize for European hop varieties of the Zhatec type and contributes to a fresh herbal aroma. That is forming an amazing bouquet of noble piquant bitterness in beer. Perlyna hop provide a perfect balance between the sweet taste of barley malt and other components that determine the style and type of beer. It has a rich herbal-floral aroma that dominates with tones of lime and sweet tones of the tropics, with a noticeable taste of ripe peach.

Conclusions

There are researches of comprehensive assessment of the quality of type 90 hop pellets that were produced in Ukraine and European countries and the most in demand in the technologies of Ukrainian beer producers, made it possible to form a database of biochemical characteristics of fine aromatic and aromatic varieties based on the absolute values of such indicators as the mass fraction of alpha acids and beta-acids and their chemical composition, xanthohumol, essential oil, as well as its components and the ratio of certain valuable hop compounds. It was determined that the mass fraction of alpha-acids in hop pellets of fine aromatic varieties ranges from 2.7% in the Hersbrucker variety to 5.3% in the Slavyanka variety pellets. A higher index of alpha-acid content was determined in the pellets of aromatic varieties Zagrava and Tradition with a range of variation of the indicator from 4.6 to 7.2% with average values of 5.9 and 6.0%, respectively. The content of beta-acids in the studied pellets ranges from 3.6% (Lyublin) to 6.6% in the pellets of the Slavianka variety. It was noted that pellets made from hop of Ukrainian varieties Slavianka and Zagrava have significantly higher, compared to pellets of foreign selection, the mass fraction of beta-acids - 6.1 and 6.6%, respectively. In the composition of the bitter substances of the studied pellets, the proportion of beta-acids is equal to or exceeds the proportion of alpha-acids, that is, they retain a positive aromaticity coefficient between the content of beta-acids and alpha-acids that consists from 0.99 (Lyublin) to 1.84 (Hersbrucker). In the studied samples of hop pellets, there is significant variability in the content of essential oil with average values from 0.49 (Clone 18) to 1.64 ml/100 g of hop pellets (Zagrava). Most of the components of essential oil of hop are hydrocarbons that are represented by monoterpenoid – myrcene and sesquiterpenoids: caryophyllene, humulene and farnesene, collectively making up from 66.6% to 78.8% of their total amount.

It was based on the analysis of the theoretical and experimental results of the research database of chemical-technological evaluation, taste and aromatic properties of hop and products of hop processing of Ukrainian and foreign varieties that have the greatest demand among brewers of Ukraine, the biochemical criteria of brewery evaluation of hop varieties of the aromatic type were determined and scientifically substantiated. The main of them are: the content and composition of bitter substances, in particular: alpha-acids and beta-acids with an indicator value in the range of 4–9%; the ratio between the number of beta and alpha acids is about 1; the mass fraction of cohumulone in the composition of alpha-acids is up to

28%; the amount of essential oil based on 1 g of alpha-acids is within 0.20–0.25 ml in the presence of a significant amount of sesquiterpenoids. The amount of farnesene in the composition of the essential oil is within 10–20%, the content of prenylated flavonoids, in particular xanthohumol, is at least 0.4%. A new variety of Perlyna hop with characteristics that corresponding of the specified criteria is presented.

Thus, the expansion of the range of hop products due to the formation of highly productive hop plantations of new varieties with defined characteristics is an important prerequisite for ensuring a sufficient level of competitiveness of Ukrainian hop products on the world market.

References

1. Nesvadba V, Olšovská J, Straková L, Charvátová J, & Trnková S. Essential oils in Czech hop varieties. Kvasny prumysl. 2021; 67(3):447-454. https://doi.org/10.18832/kp2021.67.447
2. Bocquet L, Sahpaz S, Hilbert J, Rambaud C, Rivière C. Humulus lupulus L., a very popular beer ingredient and medicinal plant: Overview of its phytochemistry, its bioactivity, and its biotechnology. Phytochemistry Reviews. 2018; 17:1047-1090. https://doi.org/10.1007/s11101-018-9584-y
3. Carbone K, Bianchi G, Petrozziello M, Bonello F, Macchioni V, Parisse B, De Natale F, Alilla R, Cravero MC. Tasting the Italian Terroir through Craft Beer: Quality and Sensory Assessment of Cascade Hops Grown in Central Italy and Derived Monovarietal Beers. Foods. 2021; 10:2085. https://doi.org/10.3390/foods10092085
4. Salanță LC, Coldea TE, Ignat MV, Pop CR, Tofană M, Mudura E, Borșa A, Pasqualone A, Anjos O, Zhao H. Functionality of Special Beer Processes and Potential Health Benefits. Processes. 2020; 8(12):1613. https://doi.org/10.3390/pr8121613
5. Nesvadba V, Charvátová J, Trnková S. Breeding of flavour hops in the Czech Republic. Kvasny prumysl, 2020; 66(6):366-371. https://doi.org/10.18832/kp2019.66.366
6. Ksenija Rutnik, Maša Knez Hrnčič & Iztok Jože Košir. Hop Essential Oil: Chemical Composition, Extraction, Analysis, and Applications. Food Reviews International. 2022; 38:sup1:529-551. https://doi.org/10.1080/87559129.2021.1874413
7. Lamberti L, Grillo G, Gallina L, Carnaroglio D, Chemat F, Cravotto G. Microwave-Assisted Hydrodistillation of Hop (Humulus lupulus L.) Terpenes: A Pilot-Scale Study. Foods. 2021;10:2726. https://doi.org/10.3390/foods10112726
8. Afonso S, Arrobas M, & Rodrigues M. Ângelo. Agronomic and chemical evaluation of hop cultivars grown under Mediterranean conditions. Spanish Journal of Agricultural Research. 2021;19(3):e0904. https://doi.org/10.5424/sjar/2021193-17528
9. Kovalev VB, Kozlik TI, Protsenko LV, Bober AV, & Kormiltsev BF. Extending and maintaining the in vitro collection of (inter)national hop varieties in Ukraine. Agricultural Science and Practice. 2020;7(3):61-71. https://doi.org/10.15407/agrisp7.03.061)
10. Bober AV, Podpryatov GI, Koltunov VA, Venger OO. Resource potential of hop varieties zoned in Ukraine and their competitiveness. Bioresources and environmental management. 2015;7(1,2):80-91. Access mode: http://journals.nubip.edu.ua/index.php/Bio/article/view/6304/6197
11. Bober A, Liashenko M, Protsenko L, Slobodyanyuk N, Matseiko L, Yashchuk N, Gunko S, & Mushtruk M. Biochemical composition of the hops and quality of the finished beer. Potravinarstvo Slovak Journal of Food Sciences. 2020; 14:307-317. https://doi.org/10.5219/1311
12. Protsenko L, Ryzhuk S, Liashenko M, Shevchenko O, Litvynchuk S, Yanse L, Milosta H. Influence of alpha acids hop homologues of bitter and aromatic varieties on beer quality. Ukrainian food journal. 2020;9(2):425-436. https://doi.org/10.24263/2304-974X-2020-9-2-13
13. Ratoshnyuk TM, Ratoshnyuk VI. Hop production – world and Ukrainian markets. Bulletin of Khmelnytskyi National University. 2022; 1:278-283. https://www.doi.org/10.31891/2307-5740-2022-302-1-46
14. Pryymachuk TY, Protsenko AV, Rudyk RI, Shtanko TA. Beer and hop industries of Ukraine: situation and integration. Bulletin of agricultural science. 2018; 4(781):61-67. https://doi.org/10.31073/agrovisnyk201804-10
15. Protsenko L, Ryzhuk S, Koshitska N, Lyashenko M, Bober A, Gunko S, & Kazmirchuk V. Comparative estimation of the quality of ukrainian and european hop pellets. Food Science and Technology. 2023; 17(2). https://doi.org/10.15673/fst.v17i2.2604
16. Ryzhuk SM, Sukhoraba VP, Nadtochiy PP, Protsenko LV, Tsybulsky VO, Ratoshnyuk TM. The state of the hop growing industry in Ukraine and the possibilities of increasing its efficiency in modern conditions. Scientific Horizons. 2019; 7(80):29-40. https://doi.org/10.33249/2663-2144-2019-80-7-29
17. Keukeleire De, Denis. Fundamentals of beer and hop chemistry. Química Nova. 2000; 23(1):108-112. https://doi.org/10.1590/S0100-40422000000100019
18. Nance RM, Setzer WN. Volatile components of aroma hops (Humulus lupulus L.) commonly used in beer brewing. J. Brew. Distilling. 2011; 2:16-22. https://doi.org/10.5897/JBD.9000010
19. Donadini G, Porretta S. Uncovering patterns of consumers' interest for beer: A case study with craft beers. Food Research International. 2017; 91:183-198. https://doi.org10.1016/j.foodres.2016.11.043
20. Dean G. Hauser, Scott R. Lafontaine & Thomas H. Shellhammer. Extraction Efficiency of Dry-Hopping, Journal of the American Society of Brewing Chemists. 2019;77(3):188-198. https://doi.org10.1080/03610470.2019.1617622
21. Humia B, Santos K, Barbosa A, Sawata M, Mendonça M, Padilha F. Beer Molecules and Its Sensory and Biological Properties: A Review. Molecules. 2019; 24(8):1568. https://doi.org/10.3390/molecules24081568
22. Júlio C. Machado, Miguel A. Faria, Isabel M.P.L.V.O. Ferreira. Hops: New Perspectives for an Old Beer Ingredient. Natural Beverages. The Science of Beverages. 2019; 13:267-301. https://doi.org/10.1016/B978-0-12-816689-5.00010-9
23. Rettberg N, Biendl M, Garbe, LA. Hop Aroma and Hoppy Beer Flavor: Chemical Backgrounds and Analytical Tools – A Review. Journal of the American Society of Brewing Chemists. 2018; 76(1):1-20. https://doi.org/10.1080/03610470.2017.1402574
24. Protsenko LV, Liashenko MI, Vlasenko AS, Hryniuk TP, Dobrovolny OO. Investigation of properties of biologically active substances and their content in cones of ukrainian hop varieties. Agricultural Science and Practice. 2018; 5(2):52-63. https://doi.org/10.15407/agrisp5.02.052
25. Paventi G, de Acutis L, de Cristofaro A, Pistillo M, Germinara G, Rotundo G. Biological Activity of Humulus lupulus (L.) Essential Oil and Its Main Components against Sitophilus granaries (L.). Biomolecules. 2020; 10(8):1108. https://doi.org/10.3390/biom10081108
26. Karabín M, Hudcová T, Jelínek L, Dostálek P. Biologically Active Compounds from Hops and Prospects for Their Use. 2016; 15(3):542-567. https://doi.org/10.1111/1541-4337.12201
27. Hrnčič M, Španinger E, Košir I, Knez Ž, Bren U. Hop Compounds: Extraction Techniques, Chemical Analyses, Antioxidative, Antimicrobial, and Anticarcinogenic Effects. Nutrients. 2019;11(2):257. https://doi.org/10.3390/nu11020257

28. Bocquet L, Rivière C, Dermont C, Samaillie J, Hilbert J.L, Halama P, Siah A, Sahpaz S. Antifungal activity of hop extracts and compounds against the wheat pathogen Zymoseptoria tritici. Industrial Crops and Products. 2018; 122:290-297. https://doi.org/10.1016/j.indcrop.2018.05.061
29. Jirovetz L, Bail S, Buchbauer G, Denkova Z, Slavchev A, Stoyanova A, Schmidt E, Geissler M. Antimicrobial testings, gas chromatographic analysis and olfactory evaluation of an essential oil of hop cones (Humulus lupulus L.) from Bavaria and some of its main compounds. 2006;74:189-201. https://doi.org/10.3797/scipharm.2006.74.189
30. Aydin T, Bayrak N, Baran E, Cakir A. Insecticidal effects of extracts of Humulus lupulus (hops) L. cones and its principal component, xanthohumol. Bulletin of Entomological Research. 2017;107(4):543-549. https://doi.org/10.1017/S0007485317000256
31. Bedini S, Flamini G, Cosci F, Ascrizzi R, Benelli G, Conti B. Cannabis sativa and Humulus lupulus essential oils as novel control tools against the invasive mosquito Aedes albopictus and fresh water snail Physella acuta. Industrial Crops and Products. 2016; 85:318-323. https://doi.org/10.1016/j.indcrop.2016.03.008
32. DeGrandi-Hoffman G, Ahmada F, Probasco G, Schantz L. The effects of beta acids from hops (Humulus lupulus) on mortality of Varroa destructor (Acari: Varroidae). Experimental and Applied Acarology. 2012; 58:407-421 https://doi.org/10.1007/s10493-012-9593-2
33. Protsenko LV, Lyashenko MI, Svirchevska OV, Hryniuk TP, Vlasenko AS. Methodology for evaluating hops and hop products. Zhytomyr. Ruta. 2020. Access mode: https://isgpnaan.org/vidavnicha-diyalnist/226.html
34. Bober AV, Mylymukha BV, Chykhman OV. Research on the quality of hops and hop products used in brewing. Scientific Bulletin of the NUBiP of Ukraine. Series: Agronomy. 2015; 210(1):221-226. Access mode: https://agriculturalscience.com.ua/uk/journals/210-ch-1-2015
35. Bober AV, Protsenko LV. Technological assessment of brewing qualities of aromatic and bitter varieties of hops and products of its processing. Scientific journal "Plant cultivation and soil science". 2016; (235):241-248. Access mode: https://agriculturalscience.com.ua/uk/journals/235-2016
36. Ting P, Ryder D. The Bitter, Twisted Truth of the Hop: 50 Years of Hop Chemistry. Journal of the American Society of Brewing Chemists. 2017; 75(3):161-180. https://doi.org/10.1094/ASBCJ-2017-3638-01
37. Salanţă LC, Tofană M, Socaci S, Mudura E, Fărcaş A, Pop C, Pop A, Odagiu A. Characterisation of hop varieties grown in Romania based on their contents of bitter acids by HPLC in combination with chemometrics approach. Czech J. Food Sci. 2015; 33(2):148-155. https://doi.org/10.17221/365/2014-CJFS
38. Analytica EBC (Analityca European Brewery Convention). Methods 7.2, 7.4, 7.5, 7.7. 6th Ed. Nürnberg, Verlag Hans Carl Getränke-Fachverlag. 2006.
39. Analytica-EBC (European Brewery Convention). Section 7 Hops, Method 7.10-Hop Oil Content of Hops and Hop Products,; European Brewery Convention; The Brewers of Europe. 2007.
40. Analytica-EBC/European Brewery Convention. Section 7 Hops, Method 7.12 - Hop Essential Oils by Capillary Gas Chromatography Flame Ionization Detection; European Brewery Convention; The Brewers of Europe. 2007.
41. Bober AV. Comparative assessment of brewing qualities of hop cones and granules type 90 aromatic and bitter varieties by the content of bitter substances. Scientific reports of NUBiP Ukraine. 2011;4(26). Access mode: https://nd.nubip.edu.ua/2011_4/titul.html
42. Lyashenko MI, Protsenko LV, Rudyk RI, Bober AV, Hrynyuk TP, Vlasenko AS. Research on bitter substances of lupulin of different hop varieties. Scientific Bulletin of the National University of Life Resources and Environmental Sciences of Ukraine. Series: Agronomy. 2017;(269):224-233. Access mode: https://agriculturalscience.com.ua/uk/journals/269-2017
43. Nele Bastgen, Tobias Becher, Stephan Drusch, Jean Titze. Usability and Technological Opportunities for a Higher Isomerization Rate of α-Acids: A Review. Journal of the American Society of Brewing Chemists. 2020; 79(1):17-25. https://doi.org/10.1080/03610470.2020.1840893
44. Junguang Hao, RA Speers, Heliang Fan, Yang Deng, Ziru Dai. A review of cyclic and oxidative ditter derivatives of alpha, iso-alpha and beta-hop acids. Journal of the American Society of Brewing Chemists. 2020; 78(2):89-102. https://doi.org/10.1080/03610470.2020.1712641
45. Lucas Mattos Duarte, Rafaella Silva Aredes, Tatiane Lima Amorim, Flávia Ferreira de Carvalho Marques, Marcone Augusto Leal de Oliveira. Determination of α- and β-acids in hops by liquid chromatography or electromigration techniques: A critical review. Food Chemistry. 2022;397:133671. https://doi.org/10.1016/j.foodchem.2022.133671
46. Rudyk RI. Extraction of xanthohumol and bitter substances from hops. Scientific Reports of the NUBiP of Ukraine. 2014; 4(46). Access mode: https://nd.nubip.edu.ua/2014_4/index.html
47. Protsenko LV, Rudyk RI, Lyashenko MI, Shtanko IP, Tsybulsky VO, Chernenko OV, Hrynyuk TP, Vlasenko AS. Atlas of Ukrainian hop varieties. 2017. Access mode: https://isgpnaan.org/vidavnicha-diyalnist/231.html.
48. Nesvadba V, Polončíková Z, Henychová A, Krofta K., Patzak J. Atlas of Czech hop varieties. Chmelařský institut s.r.o., Žatec. 2012. Access mode: http://invenio.nusl.cz/record/161364/files/nusl-161364_1.pdf
49. Nesvadba V, Krofta K, Patzak J. Atlas českých odrůd chmele. Chmelařský institut, Žatec. 2022. Access mode: http://www.chizatec.cz/atlas_chmele/cz/ChiZatec_Atlas_CZ.html
50. Die Seele des Bieres. Hopfen aus Deutschland Hopfen-Sorten aus Deutschland / CMA Centrale Marketing-Gesellschaft der deutschen Agrarwirtschaft mbH. Access mode: https://www.deutscher-hopfen.de/downloads/CMA%20Hopfensortenmappe_1.pdf
51. Algazzali V, Shellhammer T. 2016. Bitterness Intensity of Oxidized Hop Acids: Humulinones and Hulupones. J. Am. Soc. Brew. Chem. 2016; 74:36-43. https://doi.org/10.1094/ASBCJ-2016-1130-01
52. Jessika De Clippeleer, Guido Aerts. Beer's bitter compounds - A detailed review on iso-a-acids: Current knowledge of the mechanisms for their formation and degradation, Brewing Science. 2014; 67(11):167-182. Access mode: http://www.scopus.com/inward/record.url?eid=2-s2.0-84926482057&partnerID=MN8TOARS
53. Protsenko L, Janse L, Koshytska N, Ryzhuk S, Liashenko M, Bober A, Gunko S. Variability and stability of essential oil composition in Ukrainian hop varieties. Kvasny prumysl. 2023;69:811-821. https://doi.org/10.18832/kp2023.69.811

БІОХІМІЧНІ КРИТЕРІЇ ПИВОВАРНОЇ ОЦІНКИ СОРТІВ ХМЕЛЮ АРОМАТИЧНОГО ТИПУ

Л. Проценко, к.т.н., зав. відділу[1] *E-mail*: Lidiya.procenko@ukr.net
Н. Кошицька, к.с.-г.н., провідний н.с. відділу[1] *E-mail*: Ninakoshitska@gmail.com
С. Рижук, академік НААН, доктор к.с.-г.н., професор, директор інституту[1] *E-mail*: isgpo_zt@ukr.net
О. Свірчевська, н.с. відділу[1] *E-mail*: Svirchevskaya79@ukr.net
А. Бобер, к.с.-г.н., доцент кафедри[2], *E-mail*: Bober_1980@i.ua
С. Гунько, к.т.н., доцент кафедри[2], *E-mail*: cgunko@gmail.com
Л. Янсе, член кореспондент НААН, доктор біологічних наук, заступник академіка-секретаря Відділення землеробства, меліорації та механізації НААН, *E* -mail: liliya.janse@gmail.com
[1] Відділ біохімії хмелю і пива та біотехнології
Інститут сільського господарства Полісся НААН України, шосе Київське, 131, м. Житомир, Україна, 10007
[2]Кафедра технології зберігання, переробки та стандартизації продукції рослинництва
ім. проф. Б.В. Лесика
Національний університет біоресурсів і природокористування України
вул. Героїв Оборони, 13, м. Київ, Україна, 03041
[3]Національна академія аграрних наук України,
вул. Михайла Омеляновича-Павленка, 9, м. Київ, Україна, 01010,

Анотація. Із розширенням асортименту пива, все частіше пивовари використовують різноманітну хмелепродукцію нових сортів хмелю, що дає змогу отримати пиво з певними профілями смаків та ароматів. Проведені дослідження комплексної оцінки якості гранул хмелю тип 90, вироблених в Україні та країнах Європи, які є найбільш затребуваними в технологіях українських виробників пива. Це дозволило сформувати базу даних біохімічних характеристик тонкоароматичних та ароматичних сортів за абсолютними значеннями таких показників, як масова частка альфа-кислот та бета-кислот (в тому числі їх хімічний склад), ксантогумолу, ефірної олії і її компонентів та співвідношенням окремих цінних сполук хмелю. Визначено, що масова частка альфа-кислот в гранулах хмелю тонкоароматичних сортів коливається від 2,7% у сорті Херсбрукер до 5,3% в сорті Слов'янка. Більш високий показник вмісту альфа-кислот був у гранулах ароматичних сортів Заграва та Традиціон з інтервалом варіювання показника від 4,6 до 7,2% (середні значення становлять 5,9 та 6,0% відповідно). Вміст бета-кислот в досліджуваних гранулах становить від 3,6% (Люблінський) до 6,6% у гранулах сорту Слов'янка. У складі гірких речовин серед досліджуваних гранул частка бета-кислот знаходиться на рівні або перевищує частку альфа-кислот. Тобто, у них зберігається позитивний коефіцієнт ароматичності між вмістом бета-кислот та альфа-кислот, що складає від 0,99 (Люблінський) до 1,84 (Херсбрукер). У досліджуваних зразках гранул хмелю спостерігається значна варіабельність вмісту ефірної олії з середніми показниками від 0,49 (Клон 18) до 1,64 мл/100 г у гранулах хмелю Заграва. Більшість компонентів ефірної олії хмелю є вуглеводнями і представлені монотерпеноїдом – мірценом та сесквітерпеноїдами: каріофіленом, гумуленом і фарнезеном, які сукупно складають від 66,6% до 78,8% від загальної її кількості. Визначено та науково обґрунтовано біохімічні критерії пивоварної оцінки сортів хмелю ароматичного типу. Основними з них є вміст та склад гірких речовин, зокрема: альфа-кислот та бета-кислот із значенням показника в діапазоні 4–9%; співвідношення між кількістю бета- та альфа-кислот близько 1; масова частка когумулону у складі альфа-кислот не більше 28%; кількість ефірної олії з розрахунку на 1 г альфа-кислот – в межах 0,20–0,25 мл за наявності значної кількості сесквітерпеноїдів. Кількість фарнезену в складі ефірної олії в межах 10–20%, вміст пренільованих флавоноїдів, зокрема ксантогумолу не менше 0,4%. Представлено новий сорт хмелю Перлина з характеристиками, що відповідають визначеним критеріям. Розширення асортименту хмелепродукції за рахунок формування високопродуктивних насаджень хмелю нових сортів з визначеними характеристиками є важливою передумовою забезпечення достатнього рівня конкурентоспроможності української продукції хмелярства на світовому ринку.

Ключові слова: гранули хмелю тип 90, сорти хмелю, біохімічні критерії, пивоварна оцінка, гіркі речовини, ефірна олія хмелю.