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COMPARATIVE ESTIMATION OF THE QUALITY OF UKRAINIAN AND EUROPEAN HOP PELLETS

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Abstract. In Ukraine, hops are basically processed into Type 90 pellets, that are practically indistinguishable in terms of biochemical indicators from hop cones. Pellets of hop are the single domestic source of hop products that can be serve as an alternative to imported pellets and extracts that used in the Ukraine brewing. Comprehensive studies of the evaluation of Type 90 hop pellets of aromatic and bitter varieties produced in Ukraine and European countries allowed establishing that they have different biochemical compositions and consequently, different brewing value. That have been identified differences in the absolute values of indicators such as the mass fraction of alpha acids, beta acids and their composition, xanthohumol, essential oil, the ratio of valuable hop compounds: beta acids to alpha acids and components of the essential oil. It has been determined that in hop pellets of aromatic varieties, the content of alpha acids changing from 3.3% in the Klone 18 variety to 5.9% in the Hallertauer Tradition variety. The content of beta acids, in the investigated pellets, ranges from 3.6% (Klone 18) to 6.7% in the Slavyanka variety. It is established that the hop pellets made from Ukrainian varieties Zagrava and Slavyanka have significantly higher content of beta acid 6.3% and 6.7%, respectively, compared to pellets of foreign varieties. There is a significant advantage in the resin fraction of beta acids over the fraction of alpha acids in the pellets of Slavyanka, Klone 18, Zhatetsky and Zagrava varieties, that they meaning retain a positive coefficient of aromaticity between the content of beta and alpha acids that ranges from 1.18 to 1.37. The content of alpha acids ranges from 8.7% in the Polisky variety to 14.1% in the Magnum variety in the hop pellets of bitter varieties. The content of beta acids in the same pellets ranges from 4.2% to 5.9%. It has been established that the composition of alpha and beta acids in the investigated pellets changes depending on the variety. It has been proven that Ukrainian-produced hop pellets correspond to their international counterparts in terms of their characteristics. Specifically, the biochemical and technological indicators of Klone 18 hop pellets correspond to the characteristics of pellets of the Czech variety Zhatetsky, pellets made from the bitter variety Alta correspond to the biochemical indicators of German Magnum pellets but pellets of varieties such as Slavyanka and Zagrava exceed the world analogies in terms of the composition and quality of bitter substances and essential oil. Based on the comparative biochemical characteristics of Type 90 hop pellets of Ukrainian and European production, the quality of Ukrainian hop products has been found to be at a global level. Certified domestic hop products, specifically Type 90 pellets, can be used do not only by Ukrainian brewers but also by other manufacturers to create new innovative and competitive products with various functional purposes.

Key words: hop pellets type 90, quality, biochemical evaluation, bitter substances, hop essential oil, hop varieties.

Introduction. Formulation of the problem

The trend of growing beer production in the world stimulates the demand for products of the hop industry and necessitates its balanced development for supplying of requirement the brewing industry [1-3]. Taking into account that Ukraine received the status of a candidate for membership in the EU, the domestic hop industry is at the stage of entering to the system of market of hop production of the European Union. Today, hops of Ukrainian varieties, as a result of the natural, climatic conditions and historical traditions of cultivation are actively conquering the foreign market [4,5,6]. Successful integration of Ukrainian hop enterprises into the foreign market is impossible without stable quality of their products [6]. Beside, in the competition on the sales market, the winner is not the one who produces more products, but the one who makes them better in terms of quality and cheaper in price. The problem of producing high-quality hop products becomes a priority for the Ukrainian commodity producer also due to the availability of Ukrainian markets of hop for foreign commodity producers. Even in the current difficult conditions of wartime, there are new opportunities and reserves for the production and export of high-quality commercial hops and products of their processing, using which it is possible to reach a new stage of development and formation of the hop industry in the country. This will allow to increase the inflow of currency resources to the country, that is an important component of the economic recovery and reconstruction of our country. Therefore, one of the main tasks of the Ukrainian hop industry today is the production of highly efficient hop processing products and supplying their stable quality.

Analysis of recent research and publications

Currently, in Ukraine, and throughout the world, both mini- and medium-sized breweries and also powerful giant breweries, use various hop processing products in their technologies: pellets type 90, pellets enriched by lupulin of type 45, isomerized pellets, extracts: ethanolic, carbon dioxide, isomerized, reducing, hop essential oil and emulsions of essential oils [7,8]. But the most production and widespread have pellet hops, in particular pellets of type 90, that practically do not differ in chemical composition from cones [7,9-11].

The advantage of hop pellets comparison to cone of hop is significantly reduce the loss of bitter substances, essential oil and other valuable for brewing compounds during the storage process [12-14], increases the efficiency of the utilization of a complex of bitter substances at the in the beer manufacture, improves at the hop worting process of dispersion, extraction and isomerization of alpha acids that presented in the pellets [15,16] and ability to automate product dosing when using pellets [17]. Savings of hops as a result applying of pellets is about 10% [7].

Besides, the volumetric mass of granulated hops is much smaller than compressed hops, so transport and storage costs are reduced [6,18]. Nowadays, production lines of granulated hops are fully mechanized and automated.

The researches of domestic and foreign scientists have been established that beer made from hop pellets or other hop products of various varieties differs significantly in the nature of bitterness, taste and aroma [11,19-21]. This is related to the peculiarity of the biochemical composition of hop cones of these varieties, and especially with quantitative content and qualitative composition of bitter substances, polyphenolic compounds, and hop essential oil [22,23]. Each variety has its own characteristic set of aromatic and taste properties [20,24,25,26]. The different ratio of the components of these hop compounds has different effects on the taste and aroma of beer [27-29].

The unique bitter substances of hops, represented by alpha and beta acids, that are not found in other plants, give beer a characteristic bitter taste [30,31]. In the complex, hop compounds cause lightening of beer and formation of foam and also increase biological and colloidal stability during storage of the drink [30,32].

However, hops give beer not only bitterness and special taste notes [23,33], but also a specific aroma, unique spiciness and a fine hop aftertaste [26,31]. This is due to the variety of aromatic substances of hop essential oil [21,26,34]. As a result of specific composition of essential oil, each variety of hop gives beer individual taste and aromatic properties. According to the authors [32,35-37], these can be citrus, floral, fruity notes, spicy, woody, herbal aromas, depending on the varieties of hop. According to the mind of most researchers, the investigation of the content and composition of bitter substances and essential oil is considered promising in brewing because it contains valuable information for brewers [23,35].

Besides recently, the hops applying got fundamental changes, mainly due to the growing international preference for beer with a more intense taste and special aroma, that is supported by the craft brewing sector, which, in turn, is due to the different qualitative composition of essential oils of hop production of different hop varieties [1]. With the development of the new Craft beer trend [27,38] and the creation of original varieties, brewers increasingly use a variety of hop products to create special aroma profiles in beer [3], stimulating the use of a greater variety of hop processing products.

As research results show, the selection of hop pellets of different varieties to produce beer with excellent and high-quality bitterness and aroma is a relevant issue for the Brewers Association of America [15,20], European brewers [2,34,35,39,40] and Ukrainian beer producers [7,11,41].

In addition, hop cones are a powerful source of biologically active compounds that have anticancer,

antimicrobial and other biological activities [42-45]. The hops and hop products have wide pharmacological properties such as antioxidant, anti-inflammatory and anti-tumor, that are important in the pharmaceutical field [1,42,46]. Hop oil and resins are well known for their sedative and other neuropharmacological properties, but in addition, these compounds exhibit antibacterial and antifungal activity [26]. The main components of the essential oil, such as α -humulene, α -myrcene, and β -caryophyllene, showed activity against various strains of gram-positive and gram-negative bacteria [44,47,48].

Japanese scientists have been established that the beta-acids of hops delay the growth of the bacterium *Helicobacter pylori*, that infected almost half of the world's population and that is causes gastritis, stomach and duodenal ulcers. The relationship between the presence of this bacterium and the occurrence of stomach cancer has been proven [49]. These compounds have also antifungal activity. The results of the investigations about antifungal properties of hop extract (*Humulus lupulus*) that was obtained by modern scientists indicated a significant inhibition of the hyphae growth of *Aspergillus parasiticus*, *A. niger*, *Penicillium carneum*, *P. polonicum*, *P. paneum*, *P. chermesinum* and *P. roque* [50].

Also, the 2019–2023 pandemic of the Covid-19 coronavirus infection acutely posed new questions to medical science. German scientists discovered the potential of hops in the treatment of coronavirus infection, especially if the disease proceeds in a severe form and publishing the results of their work in the specialized publication *Frontiers in Plant Science* [51]. Researchers note that this plant can help to reduce the risks of the so-called cytokine storm – a powerful inadequate immune response of the body. It was found that hop cones help to reduce the activity of the most important regulator of cytokines, and this makes it possible to exclude the influence of a powerful inflammatory reaction, that provokes an immune attack on one's own tissues and cells. According to German experts, hop extract can have an antiviral effect. For example, humulon is able to suppress the replication of the virus in cells, and xanthohumol increases the effectiveness of alpha-interferon. In addition, these substances enhance the effect of certain antibiotics and have an anti-inflammatory effect due to inhibition of cyclooxygenase [51].

In the difficult conditions of the Russian aggression in Ukraine, the problem of infected wounds and burns of servicemen, which are one of the important issues for modern domestic medicine. Many researchers are investigating the new drugs with antibacterial action, especially drugs of plant origin, that, along with fairly high activity, would significantly affect the pathogenic microflora and at the same time contribute to the creation of conditions for the normalization of microbiocenosis. Ukrainian scientists proved the high antimicrobial activity of carbonated extract of hops, that

made it possible to develop on their basis an antimicrobial agent in the form of a gel for the treatment of acne and an agent in the form of an ointment for the treatment of wound infection [52,53].

The analysis of data from the world scientific literature and the results of our own research testify to a wide range and high levels of biological activity of hop compounds and substantiates the prospects utilization of the products its processing not only in brewing, but also in other areas of human activity.

Therefore, one of the main tasks that has hop industry of Ukraine today is the production of highly efficient and competitive hop processing products for their intended purpose and supplying their stable quality.

The **purpose** of the investigations was determining the complex evaluation of hop pellets type 90 of Ukrainian and European production and establishing, on the basis of biochemical criteria's, the stability of their quality and competitiveness.

To achieve the purpose, the following **objectives** were formulating:

- to determine the physico-chemical and biochemical indicators of the quality of hop pellets type 90 of Ukrainian and European production of aromatic and bitter varieties;
- to investigate the stability of quality indicators of the technological evaluation of hop pellets type 90 of Ukrainian production;
- to establish the competitiveness of domestic hop production on the basis of biochemical criteria.

Research materials and methods

The research was carried out in 2019–2023 in the accredited laboratory of the Department of Hop and Beer Biochemistry and Biotechnology of the Polyssia Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine and the production area of hop granulation at the LLC "Hop of Ukraine" and the PE "Halchyn-agro".

Biochemical indicators of the quality of hop pellets type 90 of Ukrainian production of fine aromatic varieties: Klone 18, Zlato Polissya, Slavyanka, Nationalny, aromatic variety – Zagrava and bitter type: Alta, Polisky and Ksanta were investigated. As well as hop pellets of European-produced of fine-aromatic types, that have the greatest demand among Ukrainian brewers: varieties of Zhatetsky Saaz (Czech Republic), Tettninger (Germany), Lublin (Poland), aromatic: variety of Hallertauer Tradition (Germany) and bitter: varieties of Mahnum (Germany) and Northern Brewer (UK). Samples of hop pellets of the respective varieties were selected from the consignments according to the method [54]. The weight of the average sample for identification and biochemical studies was at least 1 kg of hop pellets. The 7–10 samples from consignments of pellets of each hop variety were studding.

Modern physico-chemical methods of analysis of bitter substances, essential oil and polyphenolic compounds of hops and hop products are utilized, in

particular: high-performance liquid chromatography, capillary gas chromatography, spectrophotometry, other methods investigation that harmonized with the methods of the European Brewing Convention [54-57]. The estimation of the reliability of the obtained research results were utilize mathematical-statistical methods with using dispersion and correlation-regression analysis.

The quantity and qualitative researching of composition of bitter substances of hop granules. The quantity of alpha-acids (conductometric indicator of bitterness) was determine by the international method Analytika EBC 7.5 [54,55]. The method is based on the conductometric titration of the diethyl ether extract of bitter substances of hops with a solution of lead acetic acid and the calculation of the mass fraction of alpha acids. The content and composition of alpha-acids, beta-acids and xanthohumol – by the method of high-performance liquid chromatography according to the international method of EBC 7.7 [54,55]. Bitter substances of hops: alpha- acids and beta-acids and their components, in particular, cohumulone, colupulone and xanthohumol, by extraction from hop pellets with an organic solvent – methanol. The ratio between the mass of hop pellets and the extractant was 1:10. The amount of alpha-acids and beta-acids and the content of cohumulone in the composition of alpha-acids 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 a temperature of 35°C. A column with measuring of 100 x 2.1 mm was used, that was filled by Pinacle DV C18 sorbent of 3 μm. A solution of methanol, water and acetonitrile in the ratio 38:24:38 was used as the mobile phase. The xanthohumol standard with a content of this compound of 99.8% was used for the quantitative determination of xanthohumol and for the components of bitter substances (alpha and beta acids) – the international standard ISF-3 [55].

The quantity and qualitative researching of the composition of essential oil of hops. The amount of essential oil was determined by the international method Analytika EBC 7.10, that base on determining the content of essential oil in cm³ per 100 g of air-dry substance by obtaining essential oil by hydrodistillation with subsequent decantation and collecting it in a special collector [56].

The qualitative composition of the essential oil was determining according to the international method Analytika EBC 7.12 [57] by the gas-liquid capillary chromatography method on the Crystal 2000 M chromatograph with a FID detector. The method consists in the fractionation of the essential oil. The temperature of the thermostat is programmed from 70°C to 220°C at a rate of 4°C per min with followed by holding in isothermal regime during 40 min. A sample of hop essential oil was introducing in an amount from 0.1 μl to 0.4 μl when the chromatograph reaches the optimal regime. Consumption of chromatographic inert

gas (argon, nitrogen, helium) is from 20 cm³ to 30 cm³, hydrogen – 30 cm³ per min. The temperature of the chamber for introducing the essential oil sample is 220°C and the temperature of the detector is 250°C.

Chromatography conditions were selected in such a way as to suppling the distribution of the main components of the essential oil: myrcene, caryophyllene, farnesene and humulene.

Results of the research and their discussion

Currently, there are two modern enterprises for high-quality processing of hops in Ukraine. Both enterprises are located in the Zhytomyr region that has the central region of hop production in Ukraine. The plant for the processing of hops into the granules of the company LLC "Hop of Ukraine" with a modern packaging line locates in the Zhytomyr city. The modern equipment of the company PROBST (Germany) can be produced every hour of 500–550 kg of high-quality hop pellets. Another enterprise for the production of hop pellets locates on the farm "Elita-Hmil" in the Berdychev district of the Zhytomyr region. It is a modern complex based on the Czech hop granulation line MGL 400 that can be produce up to 300 kg of high-quality hop pellets every hour.

At these enterprises, the production of hop pellets has been established according to the technology improved by the scientists of the Polyssia Institute of Agriculture of the National Academy of Sciences that provides for the optimization of the mass fraction of moisture of hop pellets up to 7–8%. This technology promotes to improve the biochemical parameters of hop pellets and extend their shelf life.

The quality of hops and finished products is carefully monitored at each stage. At these enterprises, the HACCP and ISO 22000 food safety and quality management system has been implemented that systematizes numerous sanitary and technological norms and rules of production, facilitates current control and increases the quality and safety of the finish products, namely hop pellets type 90 to the level of international standards.

Biochemical characteristics of aromatic hop pellets of Ukrainian and European production. The most valuable compounds of hops and products of its processing are bitter substances. The most important among bitter substances are alpha-acids, that in the process of isomerization at the wort hopping transform into iso-alpha-acids, which are the main compounds of beer bitterness. About 90% of beer bitterness at the wort hopping by hops forming as a result of isomerization of alpha-acids into iso-alpha-acids and was giving beer a bitter taste [11,12,58-60]. The amount of alpha-acids is the main price-forming factor in the assessment of hops and hop products. Therefore, one of the criteria for biochemical assessment of hop is the quantity and composition of bitter substances. Biochemical characteristics of hop pellets type 90 of fine aromatic and aromatic varieties produced in Ukraine and European countries are given in Table 1.

Table 1 – Biochemical indicators of the quality of hop pellets of the aromatic type of Ukrainian and European production for 2019-2023 (average at n=3, P≥0.95± standard deviation)

No.	Granules of the variety	Mass fraction, %		β/α , EBC 7.7	Cohumulone in the composition α -acid, %	Culupulone in the composition β -acid, %	Total amount of essential oil, ml/100 g of hop granules
		α -acid, EBC 7.5	β -acid, EBC 7.7				
Granules of the finely aromatic type of hops							
1	Klone 18 (Ukraine)	3.6±0.74*	3.6±0.42	1.19	24.7±0.46	43.5±0.95	0.35±0.02
2	Zlato Polissya (Ukraine)	4.0±0.32	4.3±0.24	1.12	23.9±0.75	41.5±1.04	0.36±0.03
3	Zhatetsky Saaz (Czech Republic)	3.5±0.53	3.9±0.47	1.22	25.3±0.67	43.3±1.00	0.33±0.02
4	Tettnanger (Germany)	3.6±0.42	4.0±0.37	1.13	25.2±0.57	46.9±0.83	0.36±0.04
5	Lublin (Poland)	5.3±0.62	4.6±0.58	0.87	26.8±0.86	48.1±0.63	0.28±0.02
6	Slavyanka (Ukraine)	5.2±0.81	6.7±1.11	1.37	24.1±1.06	42.2±1.38	1.12±0.05
7	Nationalny (Ukraine)	5.3±0.72	5.1±0.88	0.98	22.2±1.00	39.4±0.49	0.72±0.04
Granules of the aromatic type of hops							
8	Zagrava (Ukraine)	5.8±0.82	6.3±0.95	1.18	25.0±2.37	46.5±3.15	1.31±0.05
9	Hallertauer Tradition (Germany)	5.9±0.41	4.8±0.65	0.89	26.3±0.72	47.4±1.66	0.80±0.04

Note: *average values of indicator X for 2019-2023 research years ± SD standard deviation

Our results of researches of the quantitative content and qualitative composition of bitter substances in hop pellets of aromatic varieties are consistent with the results of other researchers, who note that alpha-acids and beta-acids are the main representatives of hop bitter substances [30,31,39,40].

The biochemical investigations of composition of hop cones and pellets of the best aromatic varieties in the world: Klone 18 (Ukraine), Zhatetsky Saaz (Czech Republic), Lublin (Poland), Tettnanger (Germany) and hop pellets of other varieties that utilized in breweries of Ukraine showed that in fine-aromatic and aromatic varieties of hops and pellets made from them, the amount of alpha acids according to the data in the Table 1 ranges from 3.6% in Klone 18 to 5.9% in Hallertauer Tradition. The content of beta-acids in the investigated pellets ranges from 3.6% (Klone 18) to 6.7% in the pellets of the Slavyanka variety. It should be noted that hop pellets made from the Ukrainian varieties of Zagrava and Slovianka have significantly higher indicators of beta-acid content than the pellets of foreign varieties – 6.3 and 6.7%, respectively. Beta-acids are not bitter to the taste, but in the process of wort hopping, compounds are formed that have a pleasant, soft bitterness [59]. One of the main properties of beta-acids is a high antiseptic effect, that is important for increasing the stability of beer during of storage [61].

A characteristic feature of the studied varieties is that they have a positive aromaticity ratio between the content of beta-acids and alpha-acids that was greater than or close to 1. This is one of the decisive signs that assessing the brewing quality of hops and pellets. In the pellets of the varieties Zagrava, Klone 18, Zhatetsky and Slovianka, there was a significant advantage in the

resins of the part of beta-acids over the part of alpha-acids, the aromaticity coefficient between the content of beta-acids and alpha-acids was in the range of 1.18–1.37.

The composition of alpha-acids and beta-acids in the studied consignment changed depending on the variety and, first of all, this concerns the content of cohumulone in the composition of alpha-acids and culupulone in the composition of beta-acids. Thus, the part of cohumulone ranges from 22.2% in the cones of the National variety to 26.8% in the Lublinskyi variety, and culupulone, respectively, in the same varieties – from 39.4 to 47.1%. It should be noted that there was a close correlation between these components: if we had the higher the content of alpha-acids in cohumulone therefore the higher the proportion of culupulone was in the beta-acids composition [54]. The scientists and brewer's specialist from Germany, the Czech Republic, Slovenia, and the United States of America consider that the mass fraction of cohumulone in the composition of alpha acids in fine aromatic varieties should not be exceed 30% [16,62]. But other scientists, there is no unequivocal answer to this question [21].

Our results of researches show that all fine-aromatic and aromatic varieties of Ukrainian selection have the content of cohumulone is in the range of 22.2–26.8%, culupulone – from 39.4 to 46.5%, respectively. It is again confirming that Ukrainian varieties have high-quality composition of bitter substances.

The investigation of the stability of biochemical indicators of the quality of hop pellets type 90 of Ukrainian production. A necessary condition for obtaining beer of stable quality is the provision of stable quality indicators of raw materials, including

hop production. The stability of the quality indicators of hop pellets produced in Ukraine is presented on the example of consignments of pellets of the aromatic high-resin hop variety Zagrava that the most widespread in Ukraine. The cones and pellets of this variety have a high specific gravity of beta-acids in the overall bitterness index. At the content of alpha-acid of the range 5.0–9.0% [63], the ratio of beta-acids to alpha-acids is greater than 1. The unique character of bitterness and taste is due to the low content of cohumulone in the composition of alpha-acids (21.0–26.0%), that it classified as an aromatic hop. Zagrava is a universal variety in brewing, that widely used in the production of all traditional types of beer. It is considered a dual hop purpose – it can be used both for bitterness and aroma [63].

The main biochemical criteria for determining the technological evaluation of hop are the quantitative content and qualitative composition of bitter substances, xanthohumol and essential oil. In the Tables 2 and 3 presented the quality indicators and criteria determination of the biochemical evaluation of hop pellets of 9 consignments of the Zagrava variety.

It can be seen from the results presented in the

Table 2, that the consignments of hop pellets have a stable moisture and alpha-acid content. The content of alpha acids in pellets of the Zagrava variety ranges from 5.4% to 6.2%. The amount of beta-acids ranges from 6.2% to 7.0%. The part of cohumulone is from 22.8% to 26.3%, the part of colupulon is from 41.9% to 48.4%, respectively. The indicator of the ratio of the content of beta-acids to alpha-acids is 1.13–1.24.

Zagrava is one of the aromatic varieties, that has the largest amount of essential oil among the varieties of the aromatic group. The content of essential oil (Table 3) in hop pellets ranges from 1.08 to 1.54 ml/100 g of hop pellets.

The essential oil is represented by monoterpenoid – myrcene and sesquiterpenoids: caryophyllene, humulene and farnesene. The balanced composition of the aromatic oil with a sufficient amount of farnesene (11.9–15.1%) contributes to the formation of a spicy-floral aroma with a pronounced herbaceous character and fruity notes. As we can see from the results presented in the Tables 2 and 3, the amount and composition of alpha-acids, beta-acids, xanthohumol and essential oil in pellets of the Zagrava variety corresponds to the passport data of the variety [63].

Table 2 – Content and composition of bitter substances and xanthohumol in samples from consignments of hop pellets type 90 of the Zagrava variety for the year 2022 (average at n=3, P≥0.95±SD)

No.	Indicators of the quality of hop granules	Sample number from consignments of hop pellets									Average±SD
		1	2	3	4	5	6	7	8	9	
1.	Mass fraction of moisture, %	8.2*	8.7	7.8	8.4	8.5	7.8	8.0	8.2	7.7	8.14±0.35
2.	CIB (mass fraction α -acid, EBC method 7.5), %	5.8	5.9	5.7	5.5	5.6	5.4	6.0	6.2	6.1	5.80±0.27
3.	Mass fraction of α -acids, EBC method 7.7, %	5.6	5.8	5.5	5.3	5.4	5.2	5.7	5.9	6.0	5.60±0.27
4.	Mass fraction of β -acids, EBC method 7.7, %	6.4	6.7	6.2	6.5	6.6	6.5	6.7	7.0	7.0	6.62±0.26
5.	Correlation β - and / α -acid	1.14	1.16	1.13	1.23	1.22	1.24	1.17	1.18	1.16	1.18±0.04
6.	Cohumulone in the composition of α -acid, %	24.8	22.8	26.3	24.7	24.2	23.5	25.1	26.2	25.3	25.21±1.07
7.	Colupulon in the composition of β -acid %	43.1	41.9	47.4	44.5	44.2	44.0	46.3	48.4	45.3	45.43±1.29
8.	Xanthohumol, %	0.40	0.38	0.42	0.36	0.40	0.39	0.39	0.40	0.42	0.40±0.02
9.	Oxidation index of bitter substances (aging index)	0.32	0.31	0.28	0.34	0.31	0.33	0.30	0.32	0.34	0.32±0.02

Note: *value is the mean of three replicates

Table 3 – The total amount and composition of essential oil in samples from consignments of hop pellets type 90 of the Zagrava variety for the year 2022 (average at n=3, P≥0.95±SD)

No.	Indicators of the quality of hop granules	Sample number from consignments of hop pellets									Average ±SD
		1	2	3	4	5	6	7	8	9	
1	Total amount of essential oil, ml/100 g of hop granules	1.18*	1.08	1.24	1.42	1.56	1.37	1.54	1.42	1.51	1.4±0.17
2	Essential oil composition, %, incl.										
	- myrcene	38.1	34.4	36.7	36.2	39.9	35.8	36.8	35.7	37.3	36.7±1.35
	- caryophyllene	6.4	5.9	6.2	6.9	7.1	6.5	7.2	6.3	6.1	6.5±0.46
	- humulene	15.31	16.3	15.1	17.7	16.5	16.7	16.8	16.5	17.3	16.5±0.84
	- farnesena	12.8	13.3	15.2	14.7	11.9	13.8	12.9	13.1	14.6	12.9±0.60

Note: *value is the mean of three replicates

Thus, in the pellets of the aromatic hop variety Zagrava, a high-quality composition of bitter substances is combined with a delicate aroma characteristic of the best European varieties, such as Klone 18, Zhatetsky, Lublin, that testify to the high technological evaluation of the hop pellets of this variety.

Establishing the competitiveness of domestic hop products. The analysis of hop pellets produced in Ukraine and the hop-growing countries of Europe indicated that Ukrainian fine-aromatic varieties have high comparative to European ones in terms of technological evaluation, but also main indicators surpass them in many respects.

The utilization of modern methods, in particular high-performance liquid chromatography, made it possible to investigate quantitative content of bitter substances and also their qualitative composition. The

presented chromatograms (Fig. 1-2) clearly show the similarity in the quantitative and qualitative composition of bitter substances contained in the pellets of the studied varieties.

Comparative estimation of the biochemical characteristics of hop pellets of Klone 18 and Zhatetskyi (Table 4) indicating that these varieties are characterized by almost the same content of bitter substances. The amount of beta-acids exceeds the content of alpha-acids in both varieties that is maintained a positive aromaticity coefficient. Pellets of these varieties have 22.1–26.9% of cohumulone in the composition of alpha acids, that indicates in them the high manufacturability of bitter substances. Essential oil in these varieties was up to 1%. The essential oil is represented by myrcene, caryophyllene, humulene and farnesene.

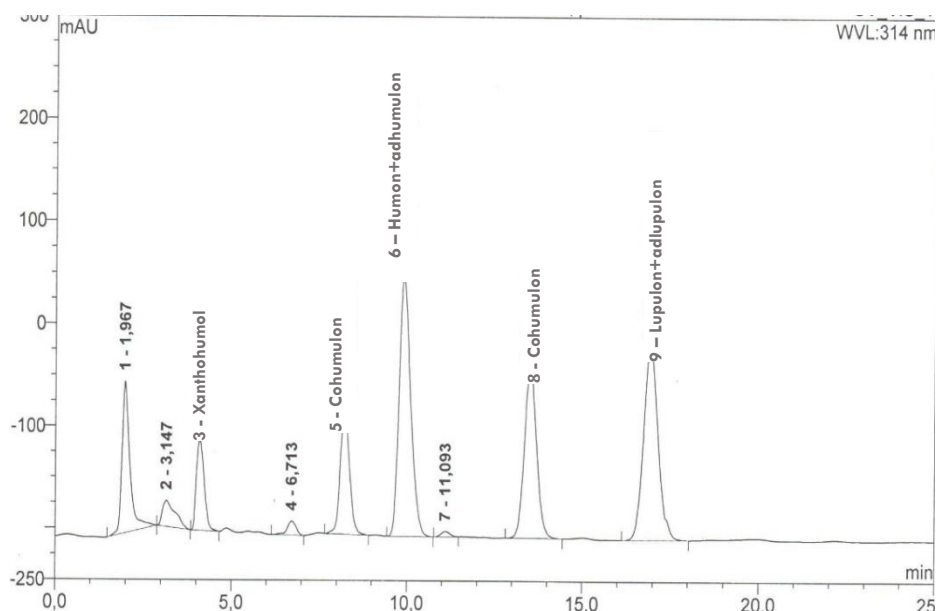


Fig. 1. Chromatogram of the composition of bitter substances in the pellets of the fine-aromatic hop variety Klone 18

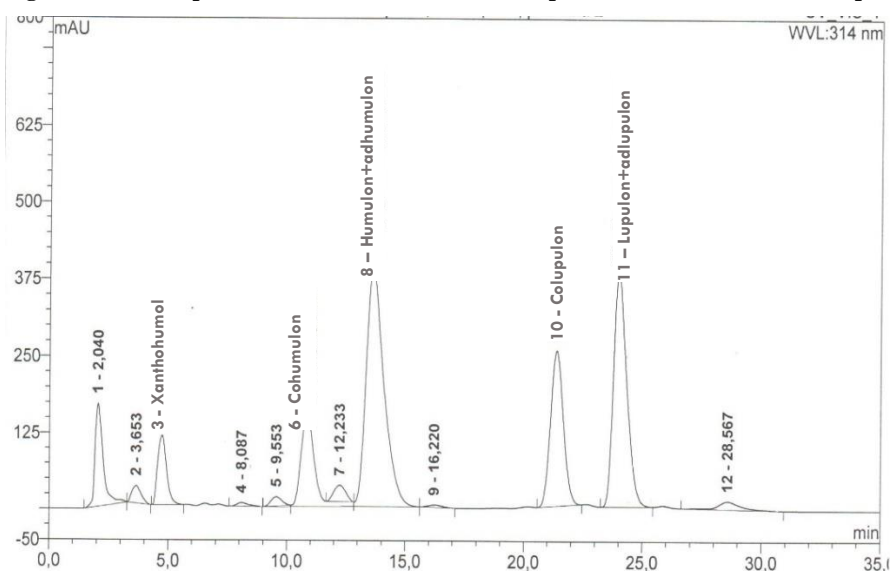


Fig. 2. Chromatogram of the composition of bitter substances in the pellets of the fine-aromatic Zhatetsky Saaz hop variety

Table 4 – Comparative biochemical characteristics of fine-aromatic hop varieties Klone 18 and Zhatetsky Saaz (2019-2023)

Quality indicators	Hop varieties	
	Klone 18 (Ukraine)	Zhatetsky* (Czech Republic)
Bitter substances, %	11.8–17.6	13.0–20.0
Alpha acids, EBC method 7.5, %	2.5–4.5	2.5–4.5
Beta acids, EBC method 7.7, %	3.0–5.6	4.0–6.0
Cohumulon in the composition of alpha acids, EBC method 7.7, %	22.1–26.9	23.0–26.0
Colupulone in the composition of beta-acids, EBC method 7.7, %	40.0–44.6	39.0–43.0
Total polyphenols, %	5.0–6.7	5.5–7.0
Xanthohumol, EBC method 7.7, %	0.3–0.5	0.3–0.5
Total amount of essential oil, ml/100 g of dry hops	0.3–0.7	0.4–0.8
Essential oil composition, %, incl.		
myrcene, %	20.0–37.0	25.0–40.0
caryophyllene, %	8.1–11.9	6.0–9.0
humulene, %	20.2–35.1	15.0–30.0
farnesene, %	14.8–21.2	14.0–20.0

* Source (64. Nesvadba, V., 2012)

Hop granules of bitter varieties, that have greatest demand among brewers, characterized by a sharp hop aroma and a high content of alpha acids from 8.9 till 14.1% (Table 5).

The amount of beta-acids is much lower than in aromatic hops. The coefficient of aromaticity between the content of beta-acids and alpha-acids for varieties of this group is 0.42 in the pellets the Magnum variety to 0.74 in the Ksanta variety, that is less than one. Granules of the bitter Polisky variety are similar to the well-known English variety of Northern Brewer in the amount and composition of bitter substances, essential oil, polyphenols and xanthohumol. The high-resin Alta variety has criteria similar to the well-known German variety of Magnum, which products are in demand among Ukrainian brewers, but has significantly less

bitter substances.

Comprehensive biochemical investigations about of the technological evaluation of hop pellets of different selection varieties promoted to establish that the pellets varieties of aromatic and bitter groups have different biochemical composition, and hence different brewing value, that is agreement with the results of other researchers [19-21,25,26].

As a result of a comparative biochemical assessment, the competitiveness of hop pellets type 90 of Ukrainian production with hop pellets type 90 produced in European countries was established. It has been proven that Ukrainian hop products correspond to the world level in terms of their characteristics and quality.

Table 5 – Biochemical indicators of the quality of hop pellets type 90 bitter varieties of Ukrainian and European production for 2019-2023 (average at n=3, P≥0.95±SD)

No.	Pellets of the hop variety	Mass fraction. %		β/α , EBC 7.7	Cohumulon in the composition of α -acid, %	Colupulone in the composition of β -acid, %	Total amount of essential oil, ml/100 g of hop pellets
		α -acid, EBC 7.5	β -acid, EBC 7.7				
Granules of bitter type of hops							
1	Polisky (Ukraine)	8.9±0.22	4.5±0.32	0.50	28.3±0.82	48.8±0.97	1.11±0.04
2	Northern Brewer (UK)	9.3±0.78	4.6±0.87	0.51	28.8±1.12	49.7±1.05	1.12 ±0.03
3	Alta (Ukraine)	9.6±1.11	4.8±1.07	0.53	25.6±1.61	45.9±1.32	1.20±0.05
4	Mahnum (Germany)	14.1±1.28	5.9±1.32	0.42	26.2±2.12	46.8±2.17	1.33±0.05
5	Ksanta (Ukraine)	9.1±1.23	5.0±0.29	0.74	29.2±0.70	52.4±2.33	0.87±0.03

Conclusion

Comprehensive studies of assessment of hop pellets type 90 of aromatic and bitter varieties produced in Ukraine and European countries promoted to establish that they have different biochemical composition, and hence different brewing value. Differences in the absolute value of such indicators as the mass fraction of alpha-acids, beta-acids and their composition, xanthohumol, essential oil, the ratio of valuable hop compounds: α -acids to β -acids and also essential oil components were established. It was determined that the content of alpha acids in hop pellets of aromatic varieties changes from 3.3% in the Klone 18 to 5.9% in the Hallertauer Tradition. The content of beta-acids in the investigated pellets ranges from 3.6% (Klone 18) to 6.7% in the Slavyanka variety. It should be noted that hop pellets made from the Ukrainian varieties of Zagrava and Slavyanka have significantly higher content of beta-acid than the pellets of foreign varieties – 6.3 and 6.7%, respectively. In the pellets of Slavyanka, Klone 18, Zhatetsky and Zagrava varieties, there is a significant advantage in the resins of the beta-acid fraction over the alpha-acid therefore they retain a positive aromaticity coefficient between the content of beta and alpha acids (1.18–1.37). The content of alpha acids in hop pellets of bitter varieties ranges from 8.7% in the Polisky variety to 14.1% in the Magnum. The content of beta-acids in the same pellets ranges from 4.2 to 5.9%. It was established that the composition of alpha-acids and beta-acids in the studied pellets changes depending on the variety.

The results of complex studies of the biochemical indicators of the quality of hop pellets type 90 of

Ukrainian production promoted to establish their high technological estimation and the conformity of the quality of Ukrainian hop products to the world level. It was established as a result of the comparison of the biochemical characteristics of hop pellets type 90 produced in Ukraine and European countries, that Ukrainian hop products correspond to world analogues, namely: hop pellets of the Klone 18 and Zlato Polissya varieties correspond to the characteristics of the pellets of Czech variety Zhatetsky in terms of biochemical and technological indicators, pellets of the bitter variety Alta, according to biochemical parameters, correspond to the pellets of the Germany variety Magnum, and the pellets of such varieties as Slavyanka and Zagrava, in terms of the composition and quality of bitter substances and essential oil, significantly exceed world analogues and are unique.

The quantitative content and qualitative composition of bitter substances, essential oil, polyphenolic compounds and xanthohumol in the hop pellets of Ukrainian production is stable and corresponds to the passport data of the hop variety from which the pellets were made.

The optimal combination of aromatic and bitter substances in cones of hops of Ukrainian selection and the high level of technology and equipment's for granulation provide the pellets with excellent brewing qualities. Certified domestic hop production, namely type 90 pellets, can be utilizing by brewing enterprises of Ukraine for the production of beer, and also by other manufacturers to create new innovative competitive products of various functional purposes and it is the prospective for exporting aim.

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ПОРІВНЯЛЬНА ОЦІНКА ЯКОСТІ ГРАНУЛ ХМЕЛЮ УКРАЇНСЬКОГО ТА ЄВРОПЕЙСЬКОГО ВИРОБНИЦТВА

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Анотація. В Україні хміль, в основному, переробляють у гранули тип 90, які практично не відрізняються за біохімічними показниками від шишкового хмелю. Для України гранули хмелю – це єдиний вітчизняний ресурс хмелепродукції, який може стати альтернативою імпортованим гранулам та екстрактам, що використовуються у пивоварінні. Проведені комплексні дослідження оцінки гранул хмелю тип 90 ароматичних та гірких сортів, вироблених в Україні та країнах Європи, дали можливість встановити, що вони мають різний біохімічний склад, а звідси і різну пивоварну цінність. Встановлено відмінності за абсолютним значенням таких показників, як масова частка альфа-кислот, бета-кислот та їх склад, ксантогумолу, ефірної олії, співвідношенням у них цінних сполук хмелю: бета-кислот до альфа-кислот, а також компонентів ефірної олії. Визначено, що в гранулах хмелю ароматичних сортів уміст альфа-кислот коливається від 3,3% у сорті Клон 18 до 5,9% в гранулах сорту Hallertauer Tradition. Уміст бета-кислот в досліджуваних гранулах становить від 3,6% (Клон 18) до 6,7% у гранулах сорту Слов'янка. Необхідно відмітити, що гранули хмелю, виготовлені з сортів української селекції Заграва та Слов'янка мають значно вищі, порівняно з гранулами закордонних сортів, показники вмісту бета-кислот – 6,3 та 6,7% відповідно. У гранулах сортів Слов'янка, Клон 18, Жатецький та Заграва є значна перевага в смолах частки бета-кислот над часткою альфа-кислот, тобто, у них зберігається позитивний коефіцієнт ароматичності між умістом бета-кислот та альфа-кислот, що складає 1,18–1,37. У гранулах хмелю гірких сортів уміст альфа-кислот коливається від 8,7% у сорті Поліський до 14,1% гранулах сорту Магнум. Уміст бета-кислот в цих же гранулах становить від 4,2% до 5,9%. Встановлено, що склад альфа-кислот та бета-кислот у досліджуваних гранулах змінюється залежно від сорту. Доведено, що гранули хмелю українського виробництва за своїми характеристиками відповідають світовим аналогам, а саме: гранули хмелю сортів Клон 18 за біохімічними та технологічними показниками відповідають характеристиці гранул чеського сорту Жатецький, гранули, виготовлені, з гіркого сорту Альта за біохімічними показниками відповідають гранулам німецького сорту Магнум, а гранули таких сортів, як Слов'янка та Заграва за складом та якістю гірких речовин та ефірної олії значно перевищують світові аналоги. На основі порівняльної біохімічної характеристики гранул хмелю тип 90 українського та європейського виробництва, встановлено відповідність якості українських хмелепродуктів світовому рівню. Сертифікована вітчизняна хмелепродукція, а саме гранули тип 90, може бути використана не лише пивоварними підприємствами України для виготовлення пива, а також іншими виробниками для створення нової інноваційної конкурентоспроможної продукції різного функціонального призначення.

Ключові слова: гранули хмелю тип 90, якість, біохімічна оцінка, гіркі речовини, ефірна олія хмелю, сорти хмелю.