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Formation of brewing qualities of Ukrainian hop varieties under the influence of weather factors

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Abstract

The brewing qualities of hop raw materials are critical in the selection of varieties for beer production. The accumulation of bitter substances, polyphenolic substances and essential oil in hop cones depends on the variety and weather conditions. In this regard, the aim of our research was to scientifically substantiate the proportion of influence of stressful weather factors and varietal characteristics on the process of forming the brewing qualities of hop cones during 2012–2022. For the study, hop cones of 9 varieties of aromatic and bitter types were selected, which were grown in the conditions of hop enterprises in the Zhytomyr region of Ukraine. It was found that in terms of bitter substances content and their variability, the most perspective from the technological point of view were Zagrava (23.0%) and Ruslan (26.1%) varieties with *Vp* = 8.0–11.7%. The maximum values of alpha-acid content were observed in the same varieties – 5.7% and 9.2%, respectively, with low and medium variability over the years of research (*Vp* = 8.7–14.0%). The highest stability in the content of polyphenolic substances (*Vp* = 6.4–8.3%) was found in the varieties Zlato Polissya and Ruslan. The content of essential oil was characterized by high variability (*Vp* up to 49.4%), the most stable were the varieties Zlato Polissya (*Vp* = 17.0%) and Ruslan (*Vp* = 22.8%). It was established that during the study period, the dominant influence on the content of bitter substances, alpha acids and essential oil was exerted by the variety (up to 69.1%), while the content of polyphenolic substances in aromatic hops was determined by weather conditions (34.3%). The results highlight the importance of varietal characteristics in the stability of the biochemical composition of hops in a changing climate. The results are of practical importance for growers and brewers, as well as for hop breeding. Resistant varieties are highly to be used more as a starting material for the creation of new hop varieties that will be more resistant to climate change and provide more stable indicators of brewing qualities of hops.

Keywords: hops; varieties; brewing qualities; bitter substances; polyphenol substances; essential oil; weather conditions; variability

1 Introduction

Hops (*Humulus lupulus* L.*)* is a herbaceous perennial plant, the female flower of which is also called hop cone or hop, used in various industries. Currently, the brewing industry accounts for 98% of global hop consumption (Contin et al., 2023; Korpelainen et al., 2021).

The growing trend in beer production in the world stimulates demand for hop production and requires its balanced development to cover the demands of the brewing industry (Salanţă et al., 2020; Humia et al., 2019; Machado et al., 2019).

In recent years, the total area under hop cultivation in Ukraine has been 300–400 hectares, and gross production in 2022–2024 amounted to 390–460 tons with an average yield of 1.3–1.6 t/ha. Currently, 16 varieties of hops are

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grown in Ukraine, and 15 of them are included to the Register of Plant Varieties (including 5 varieties of hops of foreign selection). The largest part of hop plantations in Ukraine is occupied by aromatic hop varieties – 84% of the area, and their varietal composition corresponds to the best foreign varieties. This structure is typical for the traditionally hop-growing European countries that grow aromatic raw materials (Czech Republic, Slovenia, Germany) (Ivchenko et al., 2024; Ratoshniuk, 2024).

Hop cultivation in Ukraine is concentrated within the Polissia and Forest-Steppe zones, in particular in Zhytomyr region, where up to 80% of hop cones are produced, which provide high-quality hop products for domestic brewing and are exported to other countries. The development of hop growing in Ukraine is aimed primarily at satisfying the demands of the domestic brewing industry, taking into account national centuries-old traditions, including the production of hops and hop products of valuable fine aromatic varieties (Kovalev et al., 2020).

And since Ukraine has received the status of a candidate for EU membership, domestic hop growing is at the stage of entering the EU hop market system. Due to the natural and climatic conditions and historical traditions of hop growing in Ukraine, Ukrainian hops are now actively conquering the market (Protsenko et al., 2023a; Kovalev et al., 2020; Rizhuk et al., 2019). Successful integration of Ukrainian hop enterprises into the foreign market is impossible without stable quality of their products (Rizhuk et al., 2019).

In modern market conditions, the brewing qualities of hops are of great importance, as they determine the demand for it, pricing, and financial position of producers. It is the brewing qualities of hops, which are determined by the content of such basic chemical components as bitter substances, polyphenols, and essential oil, that determine the prospects for its use as a raw material for the brewing industry (Bober et al., 2020).

Stable crop production is important for the economic income of both hop growers and traders, but it can be at risk from climate change, which can affect the quantity and quality of production (Eckardt et al., 2023; Možný et al., 2023; Potopová et al., 2021).

The unique brewing properties and wonderful aroma of Ukrainian hops obviously depend on the favorable climatic conditions of Ukraine, which are supplemented by the long-standing traditions of its cultivation. Not everywhere, even in the countries that are leaders in hop cultivation (Germany, China, and the United States), there are suitable soil and climatic conditions for the formation of high-quality hop products. Ukrainian hop varieties of aromatic and bitter groups, due to their naturally favorable climatic conditions, have long been famous for their high brewing qualities (Ratoshniuk et al., 2022; Bober et al., 2020).

More than 30 varieties of hops have been created by Ukrainian breeders, which are characterized by a wide variety of bitter substances, polyphenols, and essential oils (Protsenko, et al., 2017; Bober et al., 2015). The chemical composition of cones can change within a very wide range. It depends on the variety, soil and climatic conditions of cultivation, harvesting time, post-harvest handling technology, and storage conditions (Rizhuk et al., 2019).

It is well known that weather conditions during the formation of hop cones have a significant impact on their brewing qualities (Možný et al., 2023; Forster et al., 2021; Forster et al., 2019). But in modern times, when global climate change is taking place, this issue has become even more relevant.

Climate change not only negatively affects the conditions necessary for successful hop growth. It also affects the content of chemical components in hops that give them their natural bitterness and flavor. The brewing qualities of hop cones are determined by the content of the main chemical components such as bitter substances, polyphenols, and essential oil, as well as their ratio (Van Holle, 2021; Protsenko et al., 2020a; Takoi, 2019).

Among the complex of valuable hop compounds for beer production, bitter substances are of great importance. A significant portion of the bitter substances contained in hop cones are not found in other plants in a similar form in terms of chemical structure, physicochemical characteristics, and organoleptic properties and are unique to hops. Specific bittering substances of hops give beer its original bitterness, promote foaminess, and, together with other factors, form the characteristics of the intended beer bouquet (Klimczak et al., 2022; Sun et al., 2022; Machado et al., 2019).

In providing bitterness and other properties necessary for beer production, α-acids are of the greatest importance, but not only they, but also a range of other bitter substances, especially the β-fraction (Rutnik et al., 2022a; Protsenko et al., 2020a; Krofta et al., 2019a). Moreover, the extent to which this occurs depends on the state of these substances, their chemical transformations in hops and during the hopping of wort and beer, and the ratio of these substances in different varieties of hops and their processed products (Sawicka et al., 2021; Bober et al, 2020; Mozzon et al., 2020).

The intensity of biosynthesis of bitter substances in hop cones is influenced by environmental conditions. Scientific studies on this subject have shown that the maximum amount of bitter substances accumulates in

cones when the average daily air temperature does not exceed +16...+19 °C during flowering and formation. It is also noted that if during the period of cone formation the average daily temperature exceeds +18...+20 °C, the content of bitter substances, especially alpha acids, sharply decreases in the cones. In addition, a decrease in the average daily air temperature to +14.2 °C during the period of cone formation delays their maturation and reduces the amount of bitter substances (Liashenko et al., 2004).

Drought and irregular precipitation lead to a decrease in biosynthesis and energy in hop plants, which is reflected in a decrease in the content of bitter substances. De Keukeleire et al. (2007) and Srečec et al. (2008) investigated the influence of weather conditions on the alpha acids content during the growing season. They found an opposite correlation between average daily temperatures and alpha acid content and a strong positive correlation between total precipitation and alpha acids content. The study by Možný et al. (2009) demonstrated similar results. Kučera et al. (2009) found that July air temperatures have the greatest impact on the formation and content of alpha acids. It was found that sufficient precipitation during May, June and July has a significant impact on the content of alpha acids. Precipitation in August, the last month before harvest, had a slight effect. These conclusions may not be equally applicable to all hop growing regions, as shown by a similar study conducted on several varieties in the Czech Republic (Donner et al., 2020).

There are also data in the literature indicating that the process of accumulation of bitter substances is interconnected with the supply of moisture to plants (Liashenko et al., 2004). The lack of moisture during flowering, formation and maturation of hop cones significantly reduces the yield and content of bitter substances, in particular alpha acids (Srečec et al., 2008; De Keukeleire et al., 2007; Hniličková et al., 2000).

As noted by Liashenko (2002), depending on the variety and year of cultivation, the amount of bitter substances in hop cones varies widely. In particular, under the same conditions of agricultural technology, the accumulation of bitter substances mainly depends on the genotype and weather conditions during the growing season. And the amount of bitter substances varies less depending on weather conditions than the content of alpha acids. However, not all varieties respond equally to changes in air temperature and precipitation. Among the studied varieties, the most stable content of bitter substances and alpha acids was noted in the Polissky variety. Research by Forstera et al. (2021), found that varietal differences in climate sensitivity also have a clear impact. Newer varieties, such as Hallertau Tradition or Magnum, show slightly more stability to more difficult weather conditions than traditional varieties such as Northern Brewer and Perle.

Increased temperatures during the synthesis of bitter substances and the absence of precipitation are naturally important parameters that affect the stability of the characteristics of the variety. For example, Czech scientists (Nesvadba et al., 2021) found that elevated temperatures and absence of precipitation in the last decade have negatively affected the quantity and quality of hop varieties (Krofta et al., 2020; Krofta et al., 2019b). For this purpose, in the Czech Republic, in particular, in 2021, the research project QK21010136 was started to study and utilize new drought-resistant hop genotypes in brewing under the title '*Application of new hop varieties and genotypes resistant to drought in hop growing and beer brewing*' (Nesvadba et al., 2021). This is because assessing the stability of the technological characteristics of a hop variety is a necessary criterion for obtaining consistent beer quality.

Besides the most valuable bitter substances, hop polyphenols are of great importance. Hops polyphenols are one of the main groups of biologically active compounds that determine its extremely different, including medicinal properties. The content of total polyphenols in hop cones depends on the variety, meteorological conditions of the year, nutrition, harvesting time, quality of handling of the harvested crop, as well as on the conditions and duration of its storage. It was found that polyphenols are concentrated mainly in the petals of hop cones. The quantity of polyphenols decreases during the maturation of hop cones. Their maximum quantity is observed in the phase of cone formation, and the minimum – in the phase of physiological ripeness (Arruda et al., 2021; Abram et al., 2015; Liashenko, 2002).

The results of the investigation by Forstera et al. (2021) indicate that climatic conditions do not have a significant impact on the content of polyphenolic substances. While according to Afonso et al. (2022), the year, which represents the combined effect of several environmental variables (temperature, precipitation, relative humidity, etc.), was the most important factor for the accumulation of phenols between plants of different growth strengths and between different hop varieties.

The polyphenolic substances that are transferred to beer from hops and malt are very diverse in their weight and structure, and therefore in their properties. In total, 90 components have been identified in hop polyphenols, including those that are called tannins according to the old classification.

Of course, the taste and aroma of beer made from different varieties of hops is also affected by the different content of polyphenolic substances in them. Researchers analyzing the quality of hops depending on their polyphenol content have noted that Czech varieties contain significantly more polyphenols than hops from other countries. For example, the polyphenol content in the Czech variety Zatecky (Saaz), which is of the highest quality, is 5.2–5.9%, while in American varieties this substance is no more than 2.6%. They saw the high content of polyphenols in Zatecky hops as its advantage over other varieties (Mikyška et al., 2019). Today's scientists also state that the best quality beer is produced from hops containing about 5% polyphenols (Nardini et al., 2020).

Hop essential oil, along with bitter and polyphenolic substances, is one of the main indicators of the brewing quality of hops. Hops give beer not only a piquant bitterness and special flavor notes, but also a unique spice. This is due to the variety of essential oils and aromatic substances contained in hop cones that give beer its peculiar hop aroma. Although the proportion of these substances in the cones, depending on the breeding variety, ranges from 0.5 to 3.0 ml per 100 g of dry matter (Dovga et al., 2023; Rutnik et al., 2022b; Protsenko et al., 2017), they are crucial in the aroma of hops and beer.

The essential oil accumulates in the cones gradually, during the whole period of their formation, reaching a maximum in the period of technical ripeness of hops. Different hop varieties differ in the amount and quality of essential oil. The amount of essential oil depends on many factors, including the region and growing conditions, harvesting time, drying regimes and the shelf life of hop cones. It should be noted that the total amount of essential oil in hop varieties changes over the years, but the ratio of its components remains the same, meaning that its chemical composition is a varietal characteristic and is controlled at the genome level. Cultivation techniques, fertilization, and weather conditions affect only the amount of essential oil in hop cones, while its qualitative composition remains unchanged for a particular variety (Liashenko et al., 2004; Liashenko, 2002).

As noted previously, the qualitative composition of essential oil depends on the hop variety, that is, it has a genetic basis (Nesvadba et al, 2021; Olšovská et al, 2016), while its quantitative content can vary depending on the cultivation techniques, fertilisation, weather conditions, etc.

Thus, based on the above literature, it can be stated that there is a strong correlation between the brewing qualities of hop cones and the content of bitter substances, polyphenols and essential oil, the quantitative content of which, in turn, is strongly correlated with weather conditions and varietal characteristics. In the context of climate change, the degree of influence of stressful weather factors on the formation of brewing qualities of hop cones of different varieties in the Zhytomyr region of Ukraine is not sufficiently covered in the literature, which determines the significance of the research.

2 Materials and methods

The research was conducted during 2012–2022 with nine commercially important Ukrainian hop varieties of aromatic and bitter types, the most common in the production conditions of Ukraine. The hops of the varieties selected for the study were grown in the conditions of hop enterprises in Zhytomyr region. The hops were grown according to the same generally accepted technology, according to which the whole range of agrotechnical measures was carried out, namely, soil cultivation, fertilization, pest and disease control, and post-harvest handling were carried out in time.

2.1 Hop varieties

We studied hops of Ukrainian selection of aromatic and bitter varieties (Protsenko, et al., 2017):

Aromatic varieties:

- Klon 18 (registered in 1969),
- Zlato Polissya (registered in 2002),
- Slovianka (registered in 1995),
- National (registered in 2004),
- Zagrava (registered in 1998);

Bitter varieties:

- Alta (registered in 1996),
- Promin (registered in 2001),
- Ruslan (registered in 2003),
- Xantha (registered in 2008).

2.2 Weather conditions during the growing season

The study used meteorological data for the period from 2012 to 2022 provided by the Zhytomyr Regional Center for Hydrometeorology. The hop-growing region, which includes Zhytomyr region, is considered to be quite favorable for hop cultivation (Rizhuk et al., 2018). The Zhytomyr region is located in the Polissia and partially in the Forest-Steppe zone of Ukraine, which determines its temperate continental climate with relatively humid conditions and significant temperature fluctuations. The winter period begins in the third decade of November and lasts until the second decade of March. Strong frosts are observed in February. The winter period lasts about 111 days. Fluctuations in air temperature throughout the winter months lead to alternating warming and

freezing. Warming usually begins in the third decade of April. The period with an average daily air temperature of 15 °C is 106 days (from May 21 to September 4), with the sum of effective temperatures (above 10 °C) of 2350–2480 °C. The period with temperatures above +10 °C is 150–155 days, and the frost-free period is 160–170 days with a sum of temperatures of 2670 °C. According to long-term records, the growing season for hops in Zhytomyr region is about 160 days. In terms of precipitation, Zhytomyr region is a zone of sufficient moisture. The average annual rainfall is about 540–650 mm. During the spring and summer, 450–500 mm of precipitation falls, sometimes in the form of quite heavy rains, sometimes with hail. Years with insufficient precipitation and uneven distribution have been quite common in recent years, and it is worth noting that the shortage often occurs during important periods of crop vegetation. The hydrothermal coefficient (HTC) is 1.3–2.0.

The G.T. Selyaninov hydrothermal coefficient (HTC) is an indicator of moisture content of the territory. The hydrothermal coefficient according to G.T. Selyaninov (K) is determined by the ratio of the sum of precipitation (r) in mm for the period with an average daily air temperature above 10 °C to the sum of temperatures (Σt) for the same period, reduced in 10 times. The following ranges of Selianinov coefficient values were used in the study: K > 1.6 or more – excessively moisture; 1.3–1.6 – sufficiently moisture; 1.0–1.3 – slightly arid; 0.7–1.0 – arid; 0.4–0.7 – very arid; K < 0.4 – extremely arid (Poliovyi et al., 2012).

The dynamics of weather conditions in the region of research is shown in Figures 1–3.

Figure 1 *Dynamics of the average monthly air temperature (°C) during the hop growing season and its deviation from the norm in the Zhytomyr region for the period 2012–2022.*

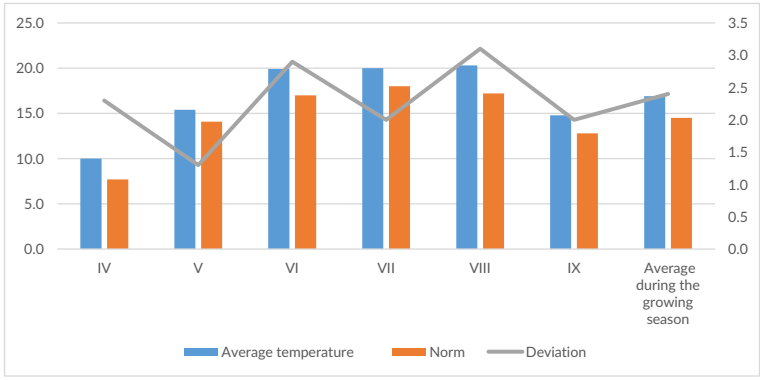


Figure 2 *Dynamics of average monthly precipitation (mm) during the hop growing season and its deviation from the norm in Zhytomyr region for the period 2012–2022.*

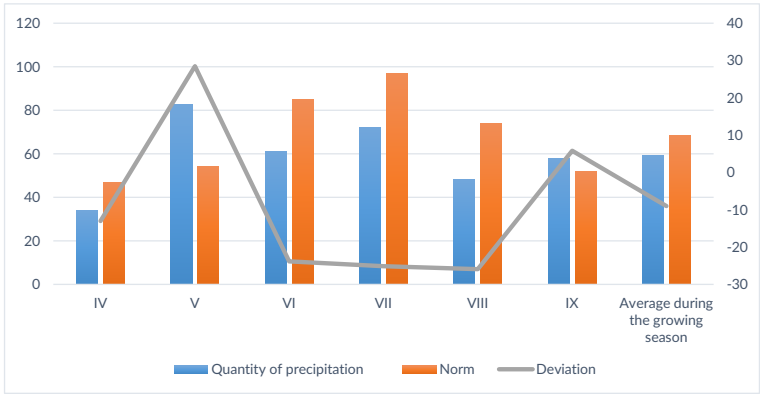
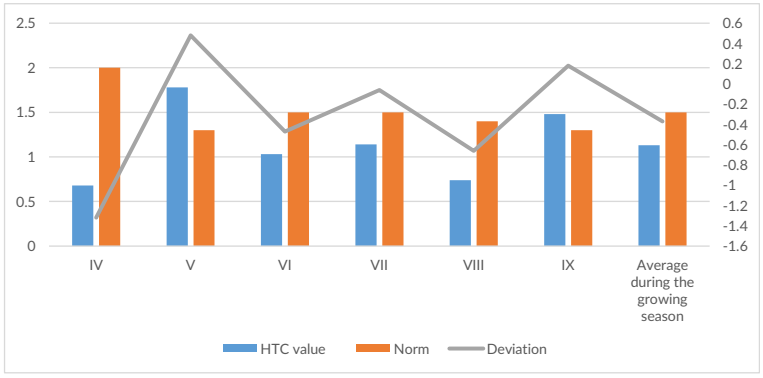


Figure 3 *Dynamics of the HTC value during the hop growing season and its deviation from the norm in Zhytomyr region for the period 2012–2022.*



Weather conditions during the years of research differed from the average long-term record. During the growing season of hop plants, the average daily air temperature exceeded the long-term average. On average, the increase over the years of research was 2.4 °C (Figure 1). The largest increase in the average monthly temperature during the hop growing season of 3.7 °C was noted in 2018, and 3.1 °C in 2015. Thus, there is a tendency to increase the average monthly temperature, which indicates a warming climate change.

As can be seen from the data presented (Figure 2), in the Zhytomyr region, during the research, an average decrease in the average monthly precipitation compared to the norm by 9.0 mm was found during the growing season. However, in May (by 28.5 mm) and September (by 5.8 mm), the average monthly precipitation was

higher than normal. There is also an unevenness of precipitation during the growing season of hops. The largest amount of precipitation during the growing season of hops falls on May–July (215.6 mm), which is 60% of the total amount of precipitation during the growing season. In the context of the studied years, the largest deviation of the average monthly precipitation from the norm for the growing season of hops was found in 2015 (-34.0 mm), 2016 (-25.6 mm) and 2017 (-26.7 mm).

The analysis of the results of the territory moisture index (HTC – hydrothermal coefficient) during the hop growing season showed that over the 11-year period, only 4 years (2013, 2014, 2020 and 2021) could be classified as wet. All other years were characterized as insufficiently wet and dry. On average, during the growing season of hops over the years of research, the HTC indicator was 1.13. Relative to the climatic norm (1.5), it decreased by 0.37 (Figure 3). Thus, the indicator of humidification of the territory corresponds to insufficiently humid conditions, which indicates a gradual change in the agroclimatic conditions of the Zhytomyr region, where the main hop plantations are concentrated.

Climate change leads to an imbalance in the established climate system of a particular region, which can have negative consequences. In particular, scientists have found an unfavorable impact of warming on hop yields and quality (Možný et al., 2023; Potopová et al., 2021; Forster et al., 2020; Forster et al., 2019).

2.3 Sample preparation and chemical analysis

Aromatic and bitter hops of Ukrainian breeding varieties of 2012–2022 harvest grown at hop enterprises of Zhytomyr region were studied. Samples were taken from industrial consignments of hops of the respective varieties during all years of experiments. Ten consignments of each variety were tested annually. One sample was taken from each consignment for analysis. To determine the quality of hop cones from each consignment, spot samples were taken from three different places of the bag (bale) that were included in the sample in approximately equal portions weighing at least 50 g. The spot samples were gently mixed to form united sample. The weight of the united sample was at least 1 kg. An average hop sample weighing about 300 g was extracted from the united sample by quartering and used to determine biochemical quality indicators (Protsenko et al., 2020b).

The total bittering content (total soft resins, hard resins, beta fraction, alpha acids, beta acids, etc.) was determined using the single sample gravimetric method in the modification of Liashenko (Protsenko et al., 2020b). The amount of alpha acids, a conductometric indicator of bitterness, was determined by the international method Analytica-EBC 7.4, which is based on the conductometric titration of hexane extract of hop bitter substances with a solution of acetic acid lead and the calculation of the mass fraction of alpha acids (Protsenko et al., 2020b; Analytica-EBC 7.4, 2019).

The total amount of polyphenolic substances was determined by the Folin method as modified by Liashenko (Protsenko et al., 2020b). The method consists of extracting polyphenols by boiling water, determining the concentration of the aqueous solution of the colored complex of hop polyphenolic substances with Folin's reagent by the optical density indicator using a photoelectrocolorimeter at 630 nm and calculating the mass fraction of polyphenols in cones.

The essential oil content was determined by the method EBC 7.10 (Analytica-EBC 7.10, 2018), which is based on the determination of the essential oil content in ml per 100 g of dry hops by obtaining essential oil by hydrodistillation, followed by decantation and collection in a special trapper. 50 g of crushed hops were weighed into a 2-liter flask and 1 liter of distilled water was added. Then the flask was connected to the distillation apparatus, and the trapper was filled with water. The hydrodistillation was carried out for 3 hours. The volume of oil was measured and determined in ml per 100 g of dry matter to two digits after the decimal point. All analyzes were performed in triplicate.

2.4 Statistical evaluation

In the analysis and processing of experimental data, methods of variation statistics were used: mathematical processing, determination of statistical characteristics, pairwise and multiple correlation and analysis of variance (ANOVA) analyses were performed using the computer programs MS Office Excel 2016, Statistica (version 10.0) and a personal computer.

3 Results and discussion

The brewing qualities of hops are determined mainly by the quantitative content and qualitative composition of bitter substances, polyphenolic substances and hop essential oil, which affect the sensory (organoleptic) properties of the finished beer, in particular its bitterness, aroma, flavor harmony and foam stability (Bober et al., 2020). Given current and forecasted trends in climate change (Eckardt et al., 2023; Možný et al., 2023; Potopová et al, 2021), climate adaptation is needed to enhance the

stability and resilience of the hop and brewing industries. In contrast to annual crops, for perennial crops such as hops, farmers and other stakeholders need more time to make decisions. Thus, the research will combine evidence on the impact of climate change-related environmental factors and climate adaptation – related hop varietal traits on hop quality to inform farmers and brewers and to adapt the hop and brewing industry.

3.1 Bitter substances

Analysis of data obtained over 11 years of research indicates that the average content of bitter substances in hop cones grown in the studied region was 20.7%, which corresponds to the global average levels (Afonso et al., 2021; Nesvadba et al., 2012).

The average content of bitter substances in the cones of aroma-type hop varieties was 19.2% (Table 1), which is 7.2% lower compared to the average varietal value. A similar trend of lower bitter substance content in aroma hop varieties compared to bitter varieties has been confirmed in other studies (Nesvadba et al., 2024; Sawicka et al., 2021; Mikyška et al., 2018).

Among the varieties of this type, the minimum content of bitter substances was recorded in the hop cones of the Klon 18 variety harvested in 2012, at 9.8%. This was 49.0% lower than the average varietal value. The maximum bitter substance content, at 28.4%, was found in the cones of the Slovianka variety from the 2019 harvest, which exceeded the average varietal value by 47.9%. Among the aroma-type varieties, Slovianka and Zagrava were characterized by the highest bitter substance content over the 11-year study period, while Klon 18 had the lowest (Table 1).

In the cones of bitter-type hop varieties, the average content of bitter substances exceeded the varietal average by 9.2%. Among these varieties, the lowest content was recorded in the cones of the Alta variety harvested in 2022, which was 31.0% below the average varietal value. The highest content was observed in the 2019 harvest of the Xantha variety, with an excess of 30.1% over the average. The highest average bitter substance content among the bitter-type varieties was found in the Ruslan variety. Similar variability depending on year and variety has also been observed by German researchers, that outlighted the significant influence of weather conditions on bitter substance content (Forster et al., 2021).

As a result, assessing the chemical composition of hop cones in terms of bitter substance content were considered particularly valuable varieties that exhibited both high levels and stability this indication over the years. The coefficient of variation (*Vp)* was used as an indicator of a variety's stability under differing meteorological conditions. It is known that a coefficient of variation below 10% indicates low or insignificant variability, 10–20% indicates moderate variability, and values above 20% indicate high or substantial variability (Blyznyuchenko, 2003). The results of the study indicate moderate interannual variability in bitter substance content among aroma-type hop varieties. The greatest influence of abiotic factors on bitter substance content was observed in the Klon 18 and National varieties, with coefficients of variation of 18.5% and 17.3%, respectively. More stable varieties in terms of bitter substance content included Zagrava, Slovianka, and Zlato Polissya, with variation coefficients ranging from 11.7% to 13.9%, consistent with findings from Czech researchers

Table 1 *Content of bitter substances in hop cones of different types and varieties (%) (2012–2022),* x ± sx, n=3

Hop variety	Average content of bitter substances (%)	*Min* content of bitter substances (%)	*Max* content of bitter substances (%)	Variation by years, *Vp* (%)
Aromatic type of hops				
Klon 18	13.0±2.4	9.8	17.4	18.5
Zlato Polissya	15.9±2.1	12.8	18.9	13.2
Slovianka	23.8±3.3	17.1	28.4	13.9
National	20.2±3.5	16.1	26.6	17.3
Zagrava	23.0±2.7	20.0	28.2	11.7
Average value	19.2±2.8	9.8	26.6	14.6
Bitter type of hops				
Alta	20.7±3.2	15.6	27.4	15.5
Promin	20.1±2.3	17.0	23.5	11.4
Ruslan	26.1±2.1	21.7	29.0	8.0
Xantha	23.4±3.2	19.4	29.4	13.7
Average value	22.6±2.7	15.6	29.4	12.0

(Nesvadba et al., 2024). The variation of bitter substances over the years of research in the cones of bitter hops was also average (*Vp* = 12.0%). Among the bitter varieties, the most stable content of bitter substances was in the cones of Ruslan hop variety (*Vp* = 8.0%). The variability of this variety under the influence of weather factors in terms of bitter substances content is considered low, which indicates its high stability to different weather conditions. In bitter varieties, the highest variability in bitter substance content was recorded in the cones of Alta hop variety (*Vp* = 15.5%).

Thus, according to the content of bitter substances and the variability of their formation under the influence of weather factors in the analyzed region, the most perspective, from the technological point of view, among aromatic varieties were Slovianka and Zagrava, and among bitter varieties Ruslan.

Table 2 shows the results of a two-factor analysis of variance that allowed us to evaluate the influence of weather conditions of the years of research (factor A), hop varietal characteristics (factor B) and their interaction (factor AB) on the formation of bitter substances in aromatic and bitter hop cones.

It was found that for aromatic hop varieties, the dominant influence on the formation of bitter substances content was the variety (factor B) with a percentage of influence of 69.1%. The weather conditions of the years of research (factor A) provided a less significant influence – 16.5%. The interaction of factors (AB) provided an average influence of 14.4%. For bitter hop varieties, the dominant factor was also the variety (factor B) with a 45.5% influence. The influence of weather conditions in the years of research was 18.1%, which corresponds to the average influence. The interaction of research factors for bitter varieties provided an influence of 36.4%.

Thus, it can be concluded that for both types of varieties, the dominant factor in the formation of bitter substances content is the variety. At the same time, for bitter hop varieties, an additional role is played by the weather conditions of the years of research and their interaction with varietal characteristics, which indicates a higher sensitivity of this type to changes in weather conditions.

3.2 Alpha Acids

Among the complex of compounds belonging to hop bittering substances, α-acids are the most valuable for brewing. They are of primary importance in the formation of beer bitterness during the wort hopping process (Klimczak et al., 2022; Možný et al., 2009; Srečec et al., 2008). The content of alpha acids is influenced by both genetic and environmental factors (Patzak et al., 2021; Donner et al. 2020; MacKinnon et al., 2020).

Studies conducted in 2012–2022 found that the average alpha-acid content in hop cones grown in the conditions of hop farms in the Zhytomyr region was 6.2%.

The average content of alpha acids in hop cones of aromatic type varieties was 4.4% and was 29.0% lower than the average varietal value (Table 3).

The minimum content of alpha acids within the aromatic type varieties was recorded in cones of Klon 18 (2.2%) from the 2012 harvest. It was lower than the average varietal value by 50.0%. The highest content of alpha acids at 7.5% was found in the cones of Zagrava hops from the 2014 harvest. At the same time, the excess over the average varietal value was 70.4%. The aroma-type varieties that accumulated the maximum amount of alpha acids, according to the results of eleven years of research, are Zagrava and National, and the lowest amount is Klon 18. The intermediate place was taken by the variety Slovianka.

Among the bitter varieties, the average alpha acids content was 8.4% and was 35.5% higher than the average varietal value (Table 3). The maximum content of alpha acids in the group of bitter varieties was recorded in cones of the 2012 harvest of Alta variety – 11.9%. The minimum values of the indicator were recorded in the cones of the 2018 harvest of the Promin variety – 5.7%. At the same

Table 2 *Results of two-factor analysis of variance in the formation of the content of bitter substances in hop cones*

Source of variation	Sum of squares	Degree of freedom	Variance	F_{fact}	$F_{tab.095}$	Influence (%)
Aromatic type of hops						
Factor A (year)	685.4	10	68.5	6854.2	1.9	16.5
Factor B (variety)	2862.2	4	715.6	71553.9	2.4	69.1
Interaction AB	596.2	40	14.9	1490.4	1.5	14.4
Bitter type of hops						
Factor A (year)	300.4	10	30.0	3004.1	1.9	18.1
Factor B (variety)	757.1	3	252.4	25238.3	2.7	45.5
Interaction AB	605.6	30	20.2	2018.7	1.6	36.4

time, the excess and decrease in relation to the average varietal value was 41.7% and 32.1%, respectively. These research results are in agreement with the conclusions of Czech researchers (Krofta et al., 2022), which note that weather conditions in some years are so different that they cause different levels of alpha acids content.

The obtained results indicate the average variability of alpha acids content for 2012–2022 in the group of aromatic varieties. The analysis of the coefficients of variation determined that the greatest influence of weather factors on the content of alpha acids was found for the National variety (*Vp* = 18.9%). The minimum coefficients of variation were recorded for Zlato Polissya and Zagrava (*Vp* = 13.5% and *Vp* = 14.0%). In general, the variability of the group of aromatic varieties under the influence of abiotic factors in terms of alpha acids content was average.

The variability of the alpha acids content in hop cones of the bitter type group was also average over the years of research with the value of the coefficient of variation *Vp* = 13.1%. In the context of bitter varieties, the maximum coefficient of variation was characteristic of hop cones of the Alta variety (*Vp* = 17.2%). In the group of bitter varieties, Ruslan was the most stable in terms of alpha acids content (*Vp* = 8.7%). Czech researchers (Nesvadba et al., 2024) also indicate in their studies that the variability of alpha acids content differs significantly from variety to variety. According to the results of their research, Vital and Herkules varieties showed the lowest coefficients of variation of 14.59% and 16.48%, respectively. While for the Golding variety, this figure reached 46.28%. They note that varieties with lower variability are more resistant to climate change.

Table 4 presents the results of a two-factor analysis of variance that allowed us to evaluate the influence of weather conditions in the years of research (factor A), hop varietal characteristics (factor B) and their interaction (factor AB) on the formation of alpha acids content in hop cones of aromatic and bitter types.

Table 3 *Alpha acids content in hop cones (%) of different types and varieties (2012–2022)*, x ± sx, n=3

Hop variety	Average alpha acids content (%)	*Min* alpha acids content (%)	*Max* alpha acids content (%)	Variation by years, *Vp* (%)
Aromatic type of hop				
Klon 18	2.9±0.5	2.2	3.9	17.2
Zlato Polissya	3.7±0.5	2.8	4.5	13.5
Slovianka	4.6±0.8	3.1	5.6	17.4
National	5.3±1.0	4.2	7.3	18.9
Zagrava	5.7±0.8	4.7	7.5	14.0
Average value	4.4±0.7	2.2	7.5	16.0
Bitter type of hops				
Alta	8.7±1.5	6.4	11.9	17.2
Promin	6.8±0.7	5.7	7.9	10.3
Ruslan	9.2±0.8	7.6	10.2	8.7
Xantha	8.9±1.2	7.1	11.1	13.5
Average value	8.4±1.1	7.2	9.4	13.1

Table 4 *Results of two-factor analysis of variance in the formation of alpha acids content in hop cones*

Source of variation	Sum of squares	Degree of freedom	Variance	F_{fact}	$F_{tab.095}$	Influence (%)
Aromatic type of hop						
Factor A (year)	44.7	10	4.5	469.8	1.9	17.4
Factor B (variety)	168.6	4	42.1	4428.7	2.4	65.6
Interaction AB	43.7	40	1.1	114.8	1.5	17.0
Bitter type of hops						
Factor A (year)	51.7	10	5.2	516.9	1.9	19.0
Factor B (variety)	119.8	3	39.9	3994.9	2.7	44.1
Interaction AB	99.1	30	3.3	330.4	1.6	36.5

The formation of alpha acids content in hop cones of aromatic varieties was dominated by varietal characteristics (factor B) with a share of influence of 65.6%. The meteorological conditions of the years of research (factor A) also had a significant effect (17.4%), as well as the interaction of factors (17.0%), which indicates a significant change in the reaction of varieties to weather conditions in different years.

For bitter hop varieties, variety (factor B) was also the dominant factor with a 44.1% effect, although its influence was less than for aromatic varieties. The weather conditions of the years of research (factor A) with a degree of influence of 19.0% and the interaction of variety and weather conditions of the years of research (factor AB) with a degree of influence of 36.5% also had a significant impact. This indicates a high sensitivity of bitter varieties to changes in growing conditions.

(Dos Santos et al., 2022) also noted in their studies that 30% of the variation in alpha acids content was observed among hop clones, while 47% was due to environmental conditions.

3.3 Polyphenol substances

The dynamics of the content of polyphenolic substances in hop cones of aromatic and bitter varieties for the period 2012–2022 was studied. The results of the research indicate that the average content of polyphenolic substances in hop cones grown in the conditions of the analyzed region was 4.6%. The average content of polyphenolic substances in hop cones of aromatic type varieties was 4.7% (Table 5), that is, 2.2% higher than the average varietal value. In hop cones of bitter type varieties, the average content of polyphenolic substances was 2.2% lower than the average varietal value.

Table 5 *Content of polyphenolic substances in hop cones (%) of different types and varieties (2012–2022)*, x ± sx, n=3

Hop variety	Average polyphenolic substances content (%)	*Min* polyphenolic substances content (%)	*Max* polyphenolic substances content (%)	Variation by years, *Vp* (%)
Aromatic type of hop				
Klon 18	5.0±0.6	4.2	6.2	12.0
Zlato Polissya	4.7±0.3	4.4	5.2	6.4
Slovianka	4.9±0.5	4.2	5.6	10.2
National	4.3±0.4	3.8	4.9	9.3
Zagrava	4.5±0.4	4.0	5.1	8.9
Average value	4.7±0.4	3.8	6.2	9.4
Bitter type of hops				
Alta	4.1±0.4	3.4	4.6	9.8
Promin	4.0±0.4	3.5	4.5	10.0
Ruslan	4.8±0.4	4.0	5.3	8.3
Xantha	5.1±0.7	4.2	6.4	13.7
Average value	4.5±0.5	3.4	6.4	11.1

Thus, for both types of hop varieties, the variety is the main factor in the formation of alpha acids content, but for bitter varieties, there is also a greater influence of the interaction of varietal characteristics with the weather conditions of the growing season, which should be taken into account when selecting varieties for specific agroclimatic conditions. The results of our research are confirmed by the results of other researchers (Krofta et al., 2022; Forster et al., 2021; Sawicka et al., 2021; Forster et al., 2020; Gahr et al., 2020) that the formation of α-acids content in hops depends on the interaction of genetic properties of the variety and growing conditions, in particular meteorological parameters of the growing season. In particular, Brazilian researchers

Among the group of aroma-type varieties, the lowest polyphenolic content was recorded in the cones of the National hop variety (3.8%) from the 2016 harvest. It was 23.7% lower than the average varietal value. The maximum level of polyphenolic substances at 6.2% was found in the cones of Klon 18 hops from the 2020 harvest. This exceeded the average varietal value by 31.9%. The aroma-type variety with the highest content of polyphenolic substances according to the results of eleven years of research was Klon 18, and the lowest was National (Table 5).

In the group of bitter type varieties, Alta was characterized by the lowest content of polyphenolic substances in hop cones collected in 2022. The content of

polyphenolic substances was less than the average varietal value by 24.4%. The maximum content of polyphenolic substances was recorded in hop cones of the Xantha variety harvested in 2019. The excess over the average varietal value was 42.2%. Among the group of bitter varieties, the maximum average content of polyphenolic substances was recorded in the cones of Xantha hops, and the minimum in the cones of Promin hops. Afonso et al. (2022) also found significant differences in the amount and composition of polyphenolic substances in hop cones between varieties.

From a technological point of view, varieties with cones that are characterized not only by a high content of polyphenolic substances but also by the stability of this indicator are of particular value for brewing (Šibalić et al., 2021; Mikyška et al., 2019).

The presented research results (Table 5) indicate insignificant variability in the content of polyphenolic substances over the years of research in the group of aromatic varieties. The greatest influence of weather factors on the content of polyphenolic substances in cones of this group was found for the varieties Klon 18 and Slovianka with coefficients of variation, *Vp* = 12.0% and *Vp* = 10.2%, respectively. The most stable in terms of polyphenolic substances content was Zlato Polissya with a coefficient of variation *Vp* = 6.4%.

were the varieties Zlato Polissya – aromatic type and Ruslan – bitter type. These varieties were characterized by a high content of polyphenolic substances and their low variability over the years of research. The varieties Klon 18, Slovianka, Xantha, in which the variability of polyphenolic substances content over the years of research was average, were characterized by their high content.

In general, it was established that the studied hop varieties are characterized by higher stability in the content of polyphenolic substances over the years of research compared to the content of bitter substances and alpha acids. This is consistent with the data of other researchers that also note the lower sensitivity of polyphenolic substances to changes in climatic conditions. In particular, Forster et al. (2021) reported that polyphenolic substances are less variable under the influence of weather changes than alpha acids and essential oil. Similar conclusions are also made by Možný et al. (2023), which indicate that polyphenolic substances are more stable than other hop components.

To determine the influence of various factors on the formation of polyphenolic substances in hop cones, a two-factor analysis of variance was conducted, taking into account the variation of weather conditions by years of research (factor A), varietal characteristics (factor B) and their interaction (factor AB) (Table 6).

Table 6 *Results of two-factor analysis of variance in the formation of the content of polyphenolic substances in hop cones*

Source of variation	Sum of squares	Degree of freedom	Variance	F_{fact}	$F_{tab.095}$	Influence (%)
Aromatic type of hop						
Factor A (year)	13.2	10	1.3	131.6	1.9	34.3
Factor B (variety)	11.1	4	2.8	277.0	2.4	28.8
Interaction AB	13.0	40	0.3	32.6	1.5	33.9
Bitter type of hops						
Factor A (year)	8.3	10	0.8	83.3	1.9	15.1
Factor B (variety)	27.4	3	9.1	914.4	2.7	49.9
Interaction AB	18.3	30	0.6	61.0	1.6	33.3

The variability of polyphenolic substances content over the years of research in hop cones of the group of bitter type varieties was average (*Vp* = 11.1%). Among the group of bitter type varieties, the most stable content of polyphenolic substances was in hop cones of Ruslan variety (*Vp* = 8.3%), and the most variable – in Xantha variety (*Vp* = 13.7%).

Thus, in terms of the content of polyphenolic substances and the variability of their formation under the influence of weather factors in the analyzed region, the most perspective from the technological point of view

For the group of aromatic varieties, the weather conditions of the years of research (factor A) had a dominant influence on the formation of polyphenolic substances with a proportion of 34.3%. Varietal characteristics (factor B) with a proportion of influence of 28.8% and the interaction of variety and weather conditions of the years of research (factor AB) with a proportion of influence of 33.9% also had a significant impact. The high value of the interaction factor indicates that the reaction of varieties to changes in weather conditions is significantly different, which indicates

the necessity of an individual selection of varieties depending on the climatic conditions of the growing region. This indicates a significant reaction of different varieties to weather conditions, which is in agreement with the results of Afonso et al. (2022), which highlight the different resistance of hop varieties to abiotic factors.

For bitter varieties, the dominant factor in the formation of polyphenolic substances content was the variety (factor B) with a factor of influence of 49.9%. The influence of weather conditions of the years of research (factor A) was less significant and equaled 15.1%. At the same time, the factor of interaction between varietal characteristics and weather conditions (factor AB) also had a significant effect (33.3%), indicating that different varieties react differently to annual abiotic conditions. Thus, for bitter-type varieties, genetic characteristics are the main factor in the stability of polyphenolic substances, while weather conditions have a less significant impact.

The results obtained indicate that the interaction of varietal characteristics with the weather conditions of the years of cultivation plays a significant role in the formation of polyphenolic substances in hops of both types of varieties, which requires producers to take into account the specifics of varieties when growing hops to ensure a stable quality indicator under climate change.

3.4 Essential oil

Hop essential oil, along with bittering and polyphenolic substances, is one of the main indicators of the brewing quality of hops. Due to the actual and predicted increase in average monthly temperatures during the hop growing season and the decrease in precipitation and its irregularity (Figures 1,2), it was very important to understand how changes in weather conditions affect the formation of essential oil content in terms of aromatic and bitter types of hop varieties.

Our research over eleven years has established (Table 7) that the average essential oil content in hop cones of the studied varieties grown in the conditions of hop farms in the Zhytomyr region was 1.24 ml/100 g, which corresponds to the well-known ranges for dual-use and brewing varieties (Herkenhoff et al., 2024; Nesvadba et al., 2021).

Table 7 *Essential oil content in hop cones (ml/100 g) of different types and varieties (2012–2022)*, x ± sx, n=3

Hop variety	Average essential oil content (ml/100 g)	*Min* essential oil content (ml/100 g)	*Max* essential oil content (ml/100 g)	Variation by years, *Vp* (%)
Aromatic type of hop				
Klon 18	0.45±0.11	0.30	0.70	24.4
Zlato Polissya	0.47±0.08	0.35	0.65	17.0
Slovianka	1.33±0.57	0.60	1.92	42.9
National	0.97±0.27	0.60	1.54	27.8
Zagrava	2.00±0.62	1.01	2.82	31.0
Average value	1.04±0.33	0.30	2.82	31.7
Bitter type of hops				
Alta	1.37±0.33	0.80	2.09	24.1
Promin	1.35±0.31	0.88	1.85	23.0
Ruslan	2.37±0.54	1.46	3.20	22.8
Xantha	0.81±0.40	0.44	1.87	49.4
Average value	1.47±0.39	0.80	3.20	26.5

The average content of essential oil in hop cones of aromatic type varieties was 1.04 ml/100 g, which was 16.1% lower than the average varietal value. Among the aroma hop varieties, the lowest essential oil content was recorded in the cones of Klon 18 (0.30 ml/100 g) from the 2013 harvest. It was 71.2% lower than the average varietal value. The maximum content of essential oil at the level of 2.82 ml/100 g was found in the cones of Zagrava hops harvested in 2019. At the same time, the excess over the average varietal value was 171.2%. Among the aromatic hop varieties, Zagrava was characterized by the highest essential oil content, and Klon 18 by the lowest (Table 7).

Among the bitter-type varieties, the average essential oil content was 1.47 ml/100 g and was 18.5% higher than the average varietal value (Table 7). The maximum content of essential oil in the group of bitter varieties was recorded in cones of the 2018 harvest of Ruslan variety – 3.2 ml/100 g. The minimum values of the indicator

were recorded in cones of the 2012 harvest of the Xantha variety – 0.44 ml/100 g. At the same time, the excess and decrease in relation to the average varietal value was 117.7% and 70.1%, respectively.

The evaluation of the biochemical composition of hop cones by the essential oil content established that the varieties with cones characterized not only by high oil content but also by the stability of this indicator are of special value. The coefficient of variation *Vp* was used as an indicator of the stability of the variety in relation to the meteorological conditions of different years of cultivation.

chemical composition of cones, including essential oil, is critically important for the brewing industry, as it determines the reproducibility of the beer aroma of each consignment.

In the course of the research, a two-factor analysis of variance was conducted to assess the influence of weather conditions in the years of research (factor A), hop varietal characteristics (factor B) and their interaction (factor AB) on the formation of essential oil content in aromatic and bitter hop cones. For both types of varieties, all studied factors had a statistically significant effect on the formation of essential oil in hop cones (Table 8).

Table 8 *Results of two-factor analysis of variance in the formation of essential oil content in hop cones*

Source of variation	Sum of squares	Degree of freedom	Variance	F_{fact}	$F_{tab.095}$	Influence (%)
Aromatic type of hop						
Factor A (year)	27.9	10	2.8	311.3	1.9	20.2
Factor B (variety)	78.7	7	11.2	1251.7	2.1	56.9
Interaction AB	30.2	70	0.4	48.0	1.4	21.8
Bitter type of hops						
Factor A (year)	7.8	10	0.8	77.5	1.9	15.0
Factor B (variety)	33.2	3	11.0	1105.5	2.7	63.7
Interaction AB	10.3	30	0.3	34.3	1.6	19.8

The results presented in Table 7 indicate a significant variation in the essential oil content over the years of research among the groups of aromatic and bitter varieties with average coefficients of variation of 31.7% and 26.5%, respectively. The greatest influence of abiotic factors on the content of essential oil in hop cones among aromatic varieties was found for the variety Slovianka with a coefficient of variation of 42.9%. The most stable in terms of essential oil content was Zlato Polissya with a coefficient of variation of 17.0%. The variability of this variety under the influence of weather factors in terms of essential oil content is considered average. Among the group of bitter type varieties, the most stable essential oil content was in cones of Ruslan variety (*Vp* = 22.8%), and the most variable – in Xantha variety (*Vp* = 49.4%).

Thus, in terms of essential oil content and variability of its formation under the influence of weather factors in the analyzed region, the most stable varieties were Zlato Polissya – aromatic type and Ruslan – bitter type. The varieties Zagrava, Slovianka, Promin, Alta, in which the variability of essential oil content over the years of research was higher, were characterized by its high content. According to Protsenko et al. (2023); Nesvadba et al. (2021); Nesvadba et al. (2020); Protsenko et al. (2020); Protsenko et al. (2020a), the stability of the

It was found that for varieties of aromatic hop type, the dominant influence on the formation of essential oil content was the variety (factor B) with a proportion of influence – 56.9%. The weather conditions of the years of research (factor A) provided a less significant influence – 20.2%. The interaction of factors (AB) provided an impact of 21.8%. For bitter hop varieties, the dominant factor was also the variety (factor B) with a proportion of influence of 63.7%. The influence of weather conditions in the years of research was 15.0%, which corresponds to the average influence. The interaction of research factors for bitter varieties provided an impact of 19.8%. A similar dominant role of genetic characteristics of the variety in the formation of essential oil content was also found by Sawicka et al. (2021) in their study of aromatic and bitter varieties, noting that weather factors are important but do not override genetic stability.

Thus, for both types of hop varieties, the dominant factor in the formation of essential oil content is the variety. The weather conditions of the years of cultivation and their interaction with the variety also have a significant impact, which indicates the necessity to take into account both varietal characteristics and weather factors when selecting varieties for cultivation in order to obtain high and stable essential oil content.

4 Conclusion

According to the content of bitter substances and variability of their formation in the conditions of Zhytomyr region of Ukraine, the most perspective, from the technological point of view, among the varieties of aromatic type was Zagrava – 23.0%, and of bitter type – Ruslan – 26.1%. These varieties were characterized by a high content of bitter substances and their low and medium variability over the years of research (*Vp* = 8.0–11.7%). The maximum content of alpha acids over the years of research among the varieties of aromatic type was noted in Zagrava – 5.7%, and bitter type – Ruslan – 9.2% at *Vp* = 8.7–14.0%.

The content of polyphenolic substances provided higher stability compared to other studied components of the biochemical composition in the context of the studied varieties by years of research with a coefficient of variation *Vp* = 6.4–13.7%, which makes it a stable indicator of quality in relation to changes in climatic conditions. In terms of polyphenolic substances content and variability of their formation under the influence of weather factors in the analyzed region, the most perspective varieties from the technological point of view were Zlato Polissya – aromatic type and Ruslan – bitter type. These varieties were characterized by a high content of polyphenolic substances (4.7% and 4.8%, respectively) and their low variability over the years of research (*Vp* = 6.4–8.3%). The varieties Klon 18, Slovianka, Xantha, in which the variability of polyphenolic substances content over the years of research was average (*Vp* = 10.2–13.7%), were characterized by their high content (5.0, 4.9 and 5.1%, respectively). Among the aromatic hop varieties, Zagrava had the highest essential oil content (2.0 ml/100 g), and among the bitter hop varieties, Ruslan had the highest content (2.37 ml/100 g). The research results indicate a significant variation in the essential oil content over the years of research among the groups of aromatic and bitter varieties with average coefficients of variation of 31.7% and 26.5%, respectively. The greatest influence of abiotic factors on the content of essential oil in hop cones among aromatic varieties was found for the variety Slovianka with a coefficient of variation of 42.9%. The most stable in terms of essential oil content was Zlato Polissya with a coefficient of variation of 17.0%. Among the group of bitter type varieties, the most stable essential oil content was in cones of Ruslan variety (*Vp* = 22.8%), and the most variable – in Xantha variety (*Vp* = 49.4%).

It was found that for aromatic and bitter hop varieties, the dominant influence on the formation of bitter substances and alpha acids was the variety (factor B) with the proportion of influence for the group of aromatic varieties – 69.1%, 65.6%, and the group of bitter varieties – 45.5%, 44.1%, respectively. The influence of weather conditions during the years of research (factor A) also had a significant impact on the studied indicators of 2 types of varieties and has a range of values of 16.5–19.0%. The interaction of variety and weather conditions of the years of research (factor AB) with a proportion of influence in the range of values 14.4–36.5%, indicates a significant change in the reaction of varieties to weather conditions of different years. The results of the research showed that the weather conditions of the years of research (factor A) had a dominant influence on the formation of polyphenolic substances for the group of aromatic varieties with a proportion of 34.3%. Varietal characteristics (factor B) with a proportion of influence of 28.8% and the interaction of variety and weather conditions of the years of research (factor AB) with a proportion of influence of 33.9% also had a significant impact. For bitter type varieties, the dominant factor in the formation of polyphenolic content was the variety (factor B) with a 49.9% influence ratio. The influence of the weather conditions of the years of research (factor A) was less significant and equaled 15.1%. At the same time, the factor of interaction between varietal characteristics and weather conditions (factor AB) also had a significant effect (33.3%), indicating that different varieties react differently to annual abiotic conditions. Thus, for bitter varieties, genetic characteristics are the main factor in the stability of polyphenolic content, while weather conditions have a lesser impact.

It was established that the formation of essential oil content for aromatic and bitter hop varieties was dominated by the variety (factor B) with a proportion of influence of 56.9% and 63.7%, respectively. The weather conditions of the research years (factor A) provided a less significant influence – 20.2% and 15.0%, respectively. The interaction of factors (AB) provided an impact of 21.8% and 19.8%, respectively.

The results obtained are of practical importance for growers and brewers, as well as for hop breeding. Resistant varieties are likely to be used more as a starting material for the creation of new hop varieties that will be more resistant to climate change and provide more stable indicators of brewing qualities of hops.

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