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Agroecological basics and productive traits of *Helianthus annuus ornamentalis* (*Multiflorus*) as a source of pharmaceutical raw materials

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ABSTRACT

The article presents the results of three-year research on the competitive testing of the modern nomenclature of hybrids of a crop new to domestic field agrocenoses - a «niche» crop - ornamental sunflower (*Helianthus multiflorous*) as a source of phytoraw material for pharmaceutical purposes. Prospects are outlined for reorienting the vector of modern domestic sunflower production from the traditional oilseed direction to the pharmaceutical one, which will make it possible to significantly reduce the saturation of domestic crop rotations with this crop, improve their ecological condition while simultaneously preserving the economic indicators of management. An assessment was made of the complex of phenological traits of the crop hybrids - the duration of the «sowing-emergence» interphase period, the duration of active flowering of inflorescences, and the total duration of the growing season of the experimental variants, as well as the plant height parameter. The plant survival coefficient during the growing season was studied as a criterion for the correspondence of the experimental variants to the ecological conditions of the growing zone; intermediate and final coefficients and indices of complex ecological tolerance, stability, and plasticity were calculated; and the most ecologically adapted and promising ornamental sunflower hybrids for cultivation under non-irrigated conditions of the Southern Steppe of Ukraine were outlined. An analysis of the elements of yield structure and the architecture of the generative part of plants was carried out in order to establish the best variants according to the criteria of multi-floweredness, yield of conditioned inflorescences, their size, and the productivity of one inflorescence and one plant. The yield of conditioned phytoraw material of ornamental sunflower (petals of male flowers in air-dry mass) was recorded, and the most productive hybrids over the study years were identified. The obtained phytoraw material was subjected to laboratory investigation for the content of the most important biologically active compounds that determine the pharmaceutical properties of ornamental sunflower phytoraw material: tocopherol (vitamin E), provitamin A (β-carotene), choline (vitamin B4), and lecithin.

Keywords: ornamental sunflower hybrids, agroecological assessment, phenological and biometric parameters, plant survival coefficient, yield and quality of products for pharmaceutical purposes.

INTRODUCTION

An analysis of the current agroecological state of the field crop rotation system allows us to draw an extremely unfavorable conclusion about the significant degree of its imbalance, which is manifested in the excessive growth of the share of highly profitable crops in them, which far from always are characterized by a loyal impact on agroecosystems (Sadova, 2021; Dymytrov, 2015; Lykhovyd et al., 2022). If we narrow the scope of the problem to the issue of the excessive presence of sunflower in them specifically, then it can already be stated with complete confidence that its saturation of crop rotations has long passed the «limit of common sense», and favorable forecasts regarding its return to the scientifically substantiated 15-16% cannot be expected, given the circumstance that today this crop is almost the only «budget-forming» one for the average domestic agricultural enterprise [Sadova, 2021; Yeremenko et al., 2017). Therefore, in our opinion, one of the few real levers of influence on such a situation is a certain «change of profession» for sunflower – the search for new, non-traditional, at the same time financially capacious and ecologically tolerant vectors of economic use of this crop, which certainly include the cultivation of the ornamental variety of sunflower (*H. multiflorous*) for the purpose of obtaining phytoraw material for pharmaceutical purposes, which has recently become widely used in medicine, and this fact has made it possible to perceive sunflower not as exclusively the most traditional technical oilseed crop for Ukraine (Yeremenko et al., 2017).

Attempts to change the «specialization» of sunflower by cultivating it as a fodder, green manure, backstage, or marker crop, for the purpose of obtaining raw material for the needs of the confectionery industry, have been known for quite a long time, and the positive experience of both domestic and foreign scientists is presented in numerous scientific works (Zhigailo and Zhigailo, 2016). The morphological features of the crop also contribute to its use as an ornamental plant for landscape design and greening (Zhovtobriukh and Melnyk, 2004). However, the medicinal properties of sunflower phytoraw material (primarily, collections of cured petals of male ligulate flowers) began to be used in official medicine only recently, namely since the global COVID-19 pandemic, when the high physiological activity of the compounds contained in it was clinically confirmed (Zhuykov and Lavrys, 2022a; Zhuikov and Lavrys, 2022b). The rather short history of the use of ornamental sunflower as a medicinal plant determines the fact that an analysis of the latest research and scientific publications indicates an almost complete absence of reliable scientific output on this problem (Pashchenko, 2007). On the domestic and global market of phytoraw material for pharmaceutical purposes, this product is represented in extremely insufficient quantities and, for the most part, is prepared from the petals of ordinary oilseed sunflower, where the content of physiologically active compounds is often significantly lower and, de facto, does not allow it to be used for medicinal purposes (Lavrys and Zhuikov, 2021). It is also logical that the technological aspects of cultivating this crop have not until now fallen within the scope of scientists' interests; therefore, scientifically substantiated aspects of its cultivation, the formation of productive traits, and the quality parameters of phytoraw material are almost absent, and there is a lack of established recommendations for the commercial cultivation of ornamental sunflower for pharmaceutical purposes in farms of different agroclimatic zones of Ukraine (Melnyk et al., 2021; Schilling, 2006). Given the ever-growing interest of agricultural producers specializing in the cultivation of such «niche» highly profitable crops, who are forced to involve individual fragmentary technological aspects from oilseed sunflower technology into the cultivation technology of ornamental sunflower simply by analogy (Schilling, 2006), we consider it necessary to develop a zonal adaptive technology for cultivating ornamental sunflower on the principles of biologization and the use of an organic concept, since it is raw material with «organic» status that is most in demand on the market of phytopharmaceutical products (Zhuykov et al., 2022).

MATERIALS AND METHODS

The research was established and conducted during 2023-2025 under the conditions of the State Enterprise Experimental Farm «Pioner» of the Institute of Climate-Oriented Agriculture of the National Academy of Agrarian Sciences of Ukraine (47°25'52.10»N, 33°44'57.77»E). The layout of the plots in the experiment was randomized, with four replications. The total area of the experimental plot is 0.66 ha, and the area of the protective strips is 0.16 ha. The number

of experimental variants is 12, corresponding to 48 experimental plots, with a total area of a first-order plot of 137.5 m^2 (length – 24.5 m, width – 5.6 m) and a record area of 100 m^2 (length – 17.9 m, width – 5.6 m). The crop sowing method was wide-row with a row spacing of 0.7 m.

The following sunflower hybrids were grown in the studies: Almera, Astra Gold, Atilla, Baver, Italian White, Centaur, Lime, Marvin, Moon Light, Red Sun, Sun Spot, Teddy Bear.

During the research, generally accepted methods for establishing and conducting field experiments and laboratory studies were followed, and the experiments carried out were accompanied by the necessary observations, measurements, and analyses of soil and plant samples.

The soil of the experimental field is southern medium-loamy slightly solonetzic chernozem on calcareous loess, characterized by the following parameters: the bulk density of the one-meter soil layer is 1.24 g/cm^3, the minimum water-holding capacity (MWHC) is 20.1% of the mass of absolutely dry soil, and the wilting point (WP) is 9.6%. The soil water-holding capacity is characterized as sufficiently high. As a result, upon drying out the soil forms a crust, and after rains and irrigations it becomes waterlogged; during plowing, ridges and clods often form, which is related to its natural solonetzicity and the narrow ratio of Ca^{2+} and Mg^{2+} (2.6–2.9). In addition, the soil is characterized by a high silt content, which causes low water permeability and high viscosity upon drying. The soil solution reaction is almost neutral (pH 7.1). Groundwater occurs at a depth of 14–20 m and has almost no influence on the water-air regime of the active moisture exchange zone. The arable soil layer contains 2.6% humus; total nitrogen, phosphorus, and potassium amount to 0.18, 0.16, and 3.3%, respectively. On average over the study years, the supply of the arable soil layer with NO_3 before sowing is assessed as low – 20.6 mg/kg, while that of P_2O_5 and K_2O is high – 66.3 and 224.9 mg/kg of soil, respectively.

Precipitation during the sunflower growing season was determined using a rain gauge installed in the experimental field. Air temperature, air humidity, and the sum of active and effective temperatures were reported according to data from the own meteorological station of SE EF "Pioner" of the ICA of NAAS, located 3.7 km from the experimental field, which is the closest to the experimental site.

The main climatic conditions by month for all years of the study are presented in Table 1.

Soil samples for moisture determination were collected using a soil auger. Sampling at the experimental plots was performed in triplicate. Samples were taken at regular intervals along the diagonal of the plot. Samples were collected layer by layer at 10-cm intervals. The content of individual groups of microorganisms in the soil and the total microbiological activity of the soil were determined by inoculation onto nutrient medium, followed by differentiation by groups and counting of grown colonies.

Phenological observations were carried out on permanently established record plots in two non-adjacent replications. The onset of a phase was taken as the time when it occurred in 10% of plants, and the full phase as when it occurred in 75% of plants. The dates of the main developmental phases of sunflower were necessarily

Table 1. Climatic conditions during the study years

Year	Month												Annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Mean monthly air temperature, °C													
2023	-0.3	-0.2	1.5	14.1	19.5	22.9	24.2	25.5	18.7	13.5	2.7	0.1	11.9
2024	-0.6	1.4	5.9	10.5	18.0	23.8	23.2	23.4	18.1	11.6	7.1	4.3	12.2
2025	0.9	2.7	7.6	9.8	14.7	24.6	24.7	23.8	20.8	15.5	4.9	1.7	12.6
Long-term average	-2.2	-1.8	3.3	10.0	16.0	19.9	21.9	21.3	16.4	9.8	4.4	1.9	10.1
Precipitation, mm													
2023	24.1	33.3	61.0	1.6	35.7	23.1	90.8	0	42.8	9.6	31.1	56.3	409.4
2024	23.0	9.8	7.3	56.0	72.8	92.6	48.7	22.1	12.1	10.4	38.0	25.9	418.7
2025	17.3	56.4	6.2	2.8	29.3	22.2	59.0	25.3	25.0	21.5	10.3	18.2	293.5
Long-term average	33.0	31.0	26.0	33.0	42.0	45.0	49.0	38.0	40.0	28.0	36.0	28.1	407.1

recorded: emergence, the 1st–6th pairs of true leaves, head formation, flowering, milk-wax ripeness of seeds, and full ripeness of seeds.

Sowing density was determined twice during the growing season on the same plots established after sowing. The first count was performed at the emergence phase, and the second before harvest. Linear growth was determined by measuring 20 plants from the soil surface to the upper part of the plant on fixed plots in two non-adjacent replications at the main growth and development phases on 10 typical plants in each replication. The leaf surface area of the crop was determined by the punch method, and leaf blade thickness with an electronic vernier caliper. Photosynthetic potential and net photosynthetic productivity were calculated. In leaf blades at the crop flowering phase, the content and fractional composition of green pigment and the enzymatic composition of the parenchyma were determined by the colorimetric method in an alcohol extract. The intensity of green coloration of the leaf blade was determined by an express method using a reference color palette.

The plant survival coefficient during the growing season was recorded by counting plant stand density on pre-established plots in three locations of the plot. Plant resistance to lodging was determined visually using the appropriate scale. Before and after the implementation of plant care practices, as well as during the harvest period, weed infestation of the sowings was determined by the quantitative-weight method (along the diagonal of the plots in tenfold replication) with differentiation by weed groups and species. For this purpose, a frame with an area of 1 m^2 was used. The number of phytophages was counted per 1 m^2, or by counting damaged plants (at the early stages of crop development). Observations were made before, after, and 5, 10, and 20 days after insecticide application during daylight hours (between 11:00 and 13:00). In the second case (at the beginning of emergence), counting was performed using measuring frames with an area of 0.25 m^2 at 16 points in the plot. The species composition of phytopathogens was established visually using an atlas, and their distribution was assessed by the percentage of damaged plants and the percentage of damaged area of the assimilation apparatus at 10 points in the plot. The intensity of visitation of flowering plants by honey bees was determined using sticky traps.

To determine the yield structure and for chemical analysis of sunflower phytoraw material, two model bundles were selected from each experimental variant, which included plants typical of the variant and which were dried to an air-dry state. The sunflower phytoraw material yield was recorded by manual harvesting of flowering heads followed by manual removal of petals under stationary conditions. Data on the yield of cured petals were adjusted to standard moisture (10%) and 100% purity. Experimental data were analysed separately for each field experiment using StatSoft Statistica 6.0. Analysis of variance (ANOVA) was used. Treatment means were compared using the least significant difference (LSD) test. Differences were considered statistically significant at $p < 0.05$. Under laboratory conditions, chemical analysis of the raw material was carried out for the content of residual amounts of active substances and metabolites of agricultural pesticides using fractional refractocolorimetry in a certified laboratory. The ecological plasticity of the experimental variants was determined using the Eberhart-Russell method as modified by Khotylova and Letun (Eberhart and Russell, 1966).

The Drought Susceptibility Index (DSI) is an index that quantifies how strongly the yield of a particular genotype (variety, line) declines under drought conditions compared with the average yield decline of all genotypes studied (Fischer and Maurer, 1978). DSI < 0.50 – highly drought-tolerant genotype; DSI = 0.51–1.0 – moderately tolerant; DSI = 1.0–1.50 – moderately susceptible; DSI > 1.50 – highly sensitive (susceptible) to drought.

$$DSI = \frac{1 - \frac{Ys}{Yp}}{1 - \frac{Xs}{Xp}} \quad (1)$$

where: *Ys* – mean yield of a particular genotype under water stress (drought) conditions; *Yp* – mean yield of the same genotype under optimal conditions (without stress, with irrigation); *Xs* – mean yield of all genotypes under drought conditions; *Xp* – mean yield of all genotypes under optimal conditions.

The drought tolerance index (TOL) is calculated as the difference between yield under unfavorable (stress) and favorable (non-stress) conditions (Rosielle and Hamblin, 1981):

$$TOL = Ys - Yp \quad (2)$$

where: *Ys* – yield of the genotype under stress/drought conditions; *Yp* – yield of the same genotype under non-stress/optimal conditions.

Yield stability index (YSI) – used to assess how consistently a particular crop variety or hybrid produces yield across different environmental conditions (Bouslama and Schapaugh, 1984):

$$YSI = \frac{Ys}{Yp} \quad (3)$$

where: *Ys* – yield of the genotype under stress/drought conditions; *Yp* – yield of the same genotype under non-stress/optimal conditions.

A high YSI (closer to 1) indicates high stability of the variety. The plant is adapted to environmental changes and is capable of producing a stable yield under both stress and optimal conditions. A low YSI (closer to 0) indicates instability. The variety is highly sensitive to external factors: under favorable conditions it can produce a record yield, but under the slightest stress (drought, diseases) yield declines sharply.

The yield index (YI) assesses the proportion of yield that a genotype retains under drought conditions compared with optimal conditions (Gavuzzi et al., 1997):

$$YI = \frac{Ys}{\bar{Y}s} \quad (4)$$

where: *Ys* – yield of the genotype under stress conditions; $\bar{Y}s$ – mean yield of all genotypes studied under the same stress conditions.

Stress tolerance index (STI) – is a selection index proposed by Fernandez (1992) that assesses the ability of a plant genotype to maintain relatively high yield under drought/stress conditions compared with non-stress conditions.

$$STI = \frac{(Ys)(Yp)}{(\bar{Y}p)^2} \quad (5)$$

where: *Ys* – genotype yield under drought/stress conditions; *Yp* – genotype yield under non-stress/well-watered conditions; $\bar{Y}p$ – mean yield of all genotypes under non-stress conditions.

bi – is an indicator of the linear response (plasticity) of a variety or hybrid to changes in growing conditions. It shows how a particular agricultural crop (or its individual variety) responds to the improvement or deterioration of the agronomic background, climatic conditions, and level of crop management (Eberhart and Russell, 1966).

$$Yij = \mu i + bi \cdot Ij + \delta ij \quad (6)$$

where: *Yij* – mean value of the trait of the i-th genotype in the j-th environment; μi – mean yield of the i-th genotype across all environments; *bi* – regression coefficient of the i-th genotype on the environmental index (i.e., the plasticity parameter itself); *Ij* – index of the j-th environment (deviation of the mean yield of all genotypes in this environment from the overall mean); δij – deviation from regression (random component).

When bi > 1 (high plasticity) – the variety is highly responsive to improved conditions; under a high agricultural background it produces the maximum yield increase, but under stress or on poor soils its yield drops sharply; bi = 1 (medium plasticity) – the change in the variety's yield is fully proportional to the change in growing conditions; bi < 1 (low plasticity) – the variety responds weakly to changes in technology or weather; it does not produce a record yield under a high agricultural background, but it ensures a stable minimum under unfavorable, droughty, or stress conditions.

The stability parameter (Sdi^2) describes the deviation from linear regression and shows the extent to which the actual yield of a genotype deviates from this expected linear response (Eberhart and Russell, 1966).

$$Sdi^2 = \{ [\Sigma_j Y_{ij}^2 - (Y_{i.})^2/n] - $$

$$- [(\Sigma_j Y_{ij} \cdot I_j)^2 / \Sigma_j I_j^2] \} / (n - 2) - S^2e / r \quad (7)$$

where: Y_{ij} – yield of the i-th genotype in the j-th environment; *n* – number of environments; I_j – index of the j-th environment; S^2e – pooled error mean square; *r* - number of replications.

Agronomic practices in the experiment were as follows: the predecessor crop was winter barley; after its harvest, soil disking was carried out to a depth of 10–12 cm, plowing to a depth of 22–24 cm, leveling of the plowed layer to a depth of 8–10 cm. Seed material of multi-flowered sunflower hybrids was used for sowing without pre-sowing treatment (dressing) with a fungicidal-insecticidal composition. Pre-sowing treatment was performed separately with a chelated micronutrient composition and a fungicidal preparation

approved for use in organic farming practice. Sowing of the crop was carried out in the mid-spring period at a soil temperature of 6–7 °C to a depth of 5 cm by the wide-row method with a row spacing of 0.7 m, with post-sowing rolling of the soil.

Crop care for sunflower consisted of measures to protect the crop from a complex of harmful organisms provided the economic threshold of harmfulness (ETH) was exceeded. Weed control was implemented through mechanical weed destruction techniques (pre- and post-emergence harrowing with striegel harrows and rotary hoes, inter-row cultivation); disease and pest control was carried out through treatments with biological preparations approved for use in organic farming (Table 2). Vegetative treatments of plants were carried out twice at the sunflower development stages «3 pairs of true leaves» and «head formation»; the working solution application rate in all cases was 250 L/ha, and when preparations were applied simultaneously, a tank mixture was prepared 30 minutes before treatment. Harvesting was performed by manual collection of flowering heads. Subsequently, under stationary laboratory conditions, petals were manually separated from the heads, followed by drying on fine-mesh trays without exposure to direct sunlight and with an artificial microclimate arranged in the laboratory room (air temperature 20–22 °C, relative humidity 75%, and air velocity in the room 0.1–0.3 m/s) with an exposure of 4 days. After curing the ornamental sunflower phytoraw material, it was brought to a conditioned state according to contamination parameters (the raw material was brought to 100% purity by cleaning on sets of laboratory sieves with round and rectangular openings), and the base moisture content (10%) was monitored using the thermostat-weight method (Figure 1).

RESULTS

One of the key indicators by which the ecological suitability of a particular crop hybrid for the moisture supply conditions at the time of crop emergence can be assessed is the duration of the «sowing - full emergence» period (Table 3). According to this indicator, the hybrids Teddy Bear and Centaur were recognized as the leaders in the experiment, with their seedlings emerging on the 6th day after sowing. The hybrids Almera and Atilla (7 days) also compared quite favorably with the other variants. The majority of the hybrids studied were characterized by the appearance of full emergence, on average over the study years, on the 8th day after sowing.

The longest «sowing – full emergence» period, according to the results of our research, was in the hybrids Lime and Red Sun (9 days), and the maximum was in the variant of the hybrid Sun Spot (10 days). As for the duration of the flowering phase of the crop's inflorescences, which directly determines both its decorative properties and productive traits, the leader in the experiment was recognized as the hybrid Baver, whose plants flowered for 54 days; the variant of the hybrid Marvin (50 days) and Teddy Bear (49 days, respectively) were somewhat inferior to it. The latter variant was recognized in the experiment as also being characterized by the longest growing season at the level of 124 days. The hybrids Atilla and Red Sun vegetated, on average, for 122–120 days, while in the remaining variants the crop plants

Table 2. Characteristics of the preparations used in the experiment

Preparation	Composition	Method and application rate
Organic fertilizer "Eco-Rost"	Strains of *Bacillus thermophiles*, *Bacillus subtilis*, phosphorus-mobilizing and nitrifying bacteria, and chelated micronutrient fertilizer (51 g/L N, 12.0 g/L K_2O, 58 g/L MgO, 50 g/L SO_3, 6.5 g/L B, 12.5 g/L Cu, 12.4 g/L Fe, 12.0 g/L Mn, 0.2 g/L Mo, 6.4 g/L Zn, 0.1 g/L Co, 66.4 g/L amino acids, 67.8 g/L organic acids (succinic, malic, tartaric, and citric), 3.3 g/L humic acids, 0.58 g/L fulvic acids, 0.0055 g/L phytohormones, 0.049 g/L polysaccharides, vitamins, cytokinins, gibberellin compounds)	Pre-sowing seed treatment - 2 L/t; vegetative foliar fertilization - 2 L/ha
Biofungicide Gaubsin-FORTE	Two strains of *Pseudomonas aureofaciens* culture with a cell titer of at least 4×10^9 CFU/mL	Vegetative spraying of plants - 2 L/ha
Biofungicide Viridin (Trichodermin)	Spores and mycelium of fungi of the genus *Trichoderma spp.* with a titer of at least 1×10^8 CFU/mL and metabolic products - biologically active substances	Pre-sowing seed treatment - 5 L/t; vegetative spraying of plants - 2 L/ha
Bioinsecticide Aktarofit	A complex of natural avermectins produced by the beneficial soil fungus *Streptomyces avermitilis* (abamectin - 50%, emamectin - 50%). Total toxin content not less than 1.8%	Spraying of plants - 0.2 L/ha



Figure 1. Technological chain for bringing the commercial yield of multi-flowered sunflower phytoraw material to base conditions

Table 3. Main phenological and biometric indicators of multi-flowered sunflower hybrids (average for 2023–2025)

Hybrid	Duration, days			Mean plant height, cm
	Sowing - emergence	Flowering	Total growing season	
Almera	7	43	117	138.5
Astra Gold	8	42	110	148.8
Atilla	7	39	122	151.1
Baver	8	54	111	148.2
Italian White	8	35	109	144.4
Centaur	6	34	121	156.2
Lime	9	42	118	135.6
Marvin	8	50	116	157.0
Moon Light	8	37	112	147.7
Red Sun	9	44	120	152.3
Sun Spot	10	40	119	156.3
Teddy Bear	6	49	124	133.9
LSD_{05}	0.68			4.14

ceased vegetation against a background of significant deficiency of soil and air moisture much earlier (109–118 days). According to the parameter of mean plant height, which also determines both the decorative traits of a particular experimental variant and the technological suitability for manual harvesting of phytoraw material, all hybrids were differentiated by us into the following groups: short-stemmed (130–140 cm) – Almera, Lime, Teddy Bear; medium-stemmed (140–150 cm) – Astra Gold, Baver, Italian White, Moon Light; tall (above 150 cm) – Atilla, Centaur, Marvin, Red Sun, and Sun Spot.

The average value of the plant survival rate for the experimental variants allows us to draw a conclusion about the complex ecological plasticity of a particular hybrid to the abiotic and biotic factors of the agrocenosis (Figure 2).

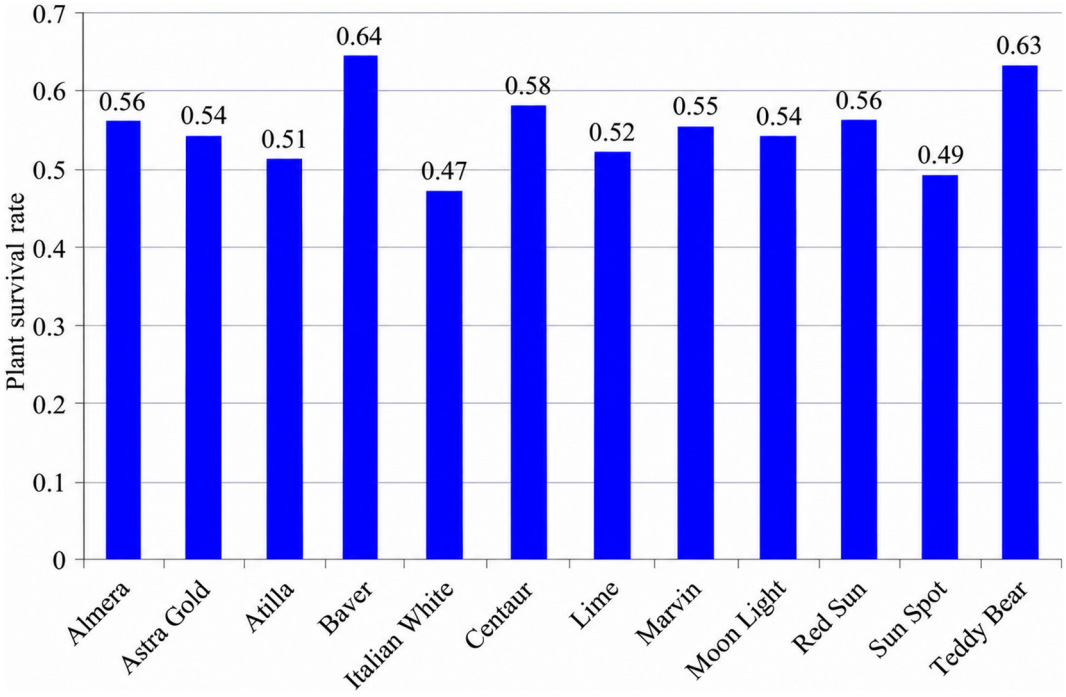

Figure 2. Survival rate of ornamental sunflower hybrid plants (average for 2023–2025)

The maximum plant survival rate in the experiment was recorded for the hybrid variants Baver and Teddy Bear (0.63–0.64), while the minimum was recorded for the hybrid variants Italian White and Sun Spot, in the sowings of which we noted plant survival during the growing season at the level of 47–49%.

Analysis of the structural parameters of the generative part of ornamental sunflower hybrid plants allows us to conclude that the maximum number of inflorescences per plant was characteristic of the hybrids Marvin (3.4 pcs.), Teddy Bear (3.3 pcs.), and Italian White (3.1 pcs./plant), while the minimum was characteristic of the hybrids Astra Gold and Atilla (2.3–2.4 pcs. per plant, respectively) (Table 4). According to the parameter of the yield of conditioned inflorescences suitable for subsequent manual picking, the hybrids Teddy

Table 4. Architecture of the generative part of multi-flowered sunflower hybrid plants (average for 2023–2025)

Hybrid	Number of flower heads per plant, pcs.	Yield of conditioned inflorescences (diameter >50 mm), %	Head weight, g	Head diameter, cm	Weight of petals from one head in air-dry state, g	Weight of petals from one plant in air-dry state, g
Almera	2.5	62.0	40.7	11.1	1.0	2.5
Astra Gold	2.3	63.4	37.4	11.3	1.1	2.5
Atilla	2.4	68.8	44.7	11.7	1.3	3.1
Baver	3.0	75.1	39.3	12.2	1.6	4.8
Italian White	3.1	72.0	40.9	9.0	0.8	3.4
Centaur	2.9	60.6	40.8	10.4	1.1	2.4
Lime	2.6	72.6	47.7	9.4	0.8	3.6
Marvin	3.4	65.5	51.7	9.9	0.9	2.9
Moon Light	3.0	70.4	55.0	10.7	1.1	3.3
Red Sun	2.5	70.1	52.8	11.0	1.3	3.2
Sun Spot	2.8	57.8	46.9	9.6	1.0	2.7
Teddy Bear	3.3	77.2	59.4	11.6	1.6	5.2
LSD 05	0.27		2.63	0.84	0.08	0.31

Bear, Baver, Lime, and Italian White stood out favorably in the experiment, in which 70–77% of flowering heads met this requirement.

According to the parameter of the mass of one inflorescence, the absolute leader in the experiment is the hybrid Teddy Bear – due to the specific structure of the head (semi-spherical shape, almost complete absence of female flowers, and fullness of the central part of the head), the average mass of a flowering inflorescence over the study years was, on average, 59.4 g. Also, according to this parameter, the variants of the hybrids Moon Light – 55.0 g, Red Sun – 52.8 g, and Marvin – 51.7 g should be highlighted in the experiment. As for the parameter of the average head diameter, which will determine both the decorative properties of a particular hybrid and hypothetically the productivity of phytoraw material (petals of male flowers), according to this parameter the leader in the experiment was recognized as the variant of the hybrid Baver, whose average inflorescence diameter over the study years was 12.2 cm; the variants of the hybrids Atilla and Teddy Bear should also be noted – 11.7 and 11.6 cm, respectively.

The maximum yield of male petals from one inflorescence in the air-dry state was noted in the experiment for two variants of the crop hybrids - Baver and Teddy Bear: on average over the study years it was 1.6 g; the hybrids Atilla and Red Sun were somewhat inferior to them (1.3 g, respectively). The absolute majority of the other hybrids were characterized by a petal mass from one inflorescence at the level of 1.0 g or less. The final parameter - the productivity of one plant, which took into account simultaneously both the number of inflorescences per plant and the mass of air-dry petals from each of them – had the following gradation: the leader in the experiment was recognized as the hybrid Teddy Bear (5.2 g of conditioned phytoraw material per plant), in second place the hybrid Baver with a value of 4.8 g, in third – the hybrid Lime (3.6 g).

It is obvious and well known that the biological yield of any crop does not in any way correspond to the real production yield, which would take into account both the peculiarities of the course of the growing season (primarily, plant survival per unit of sown area under the influence of a complex of abiotic and biotic environmental factors) and certain nuances of harvesting (primarily, harvesting losses, the departure of the non-conditioned part of the yield, etc.). The final results of accounting for the yield of conditioned phytoraw material of ornamental sunflower for the variants of the crop hybrids studied are presented by us in Figure 3. On average over the study years, the hybrids characterized by the maximum

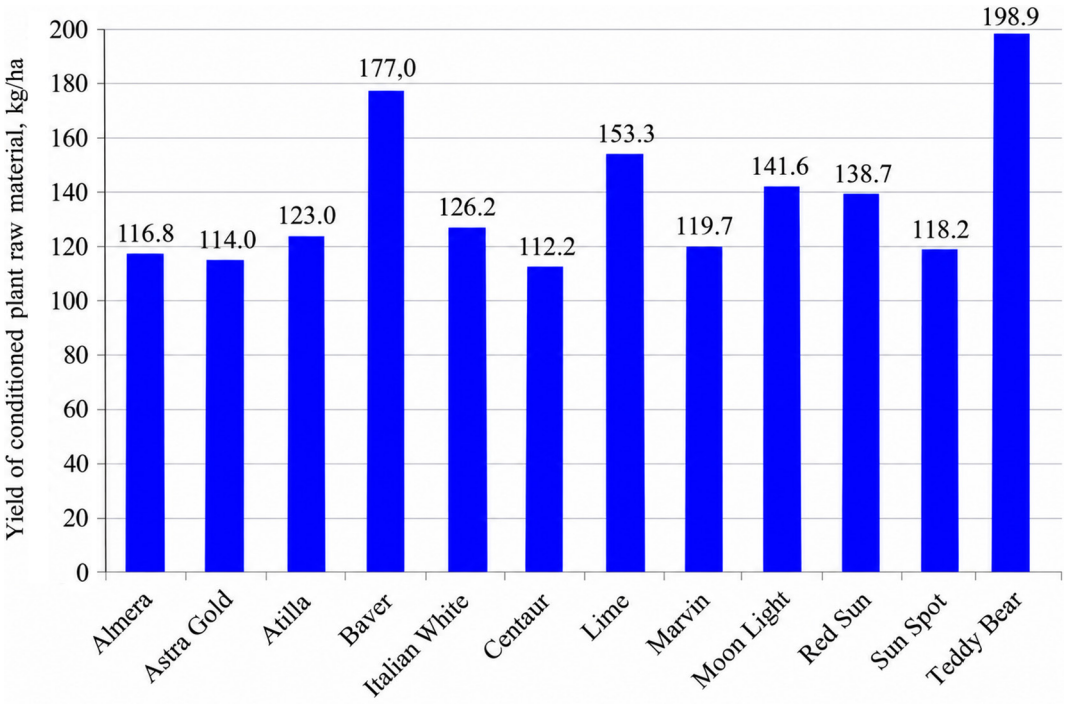

Figure 3. Yield of conditioned plant raw material of ornamental sunflower hybrids, kg/ha (LSD_{05} = 1.12 kg/ha) (average for 2023–2025)

yield of conditioned phytoraw material for pharmaceutical purposes (petals of male ligulate flowers in the air-dry state) were recognized by us as the following variants: Teddy Bear – 198.9 kg/ha, Baver – 177.0 kg/ha, and Lime – 153.3 kg/ha, respectively. The hybrids Moon Light and Red Sun (141.6 and 138.7 kg/ha, respectively) were recognized by us as promising according to the productivity parameter.

The hybrids that were significantly inferior in phytoraw material yield to the leaders of the competitive trial and whose productivity, on average over the study years, did not exceed 120 kg/ha were recognized as the hybrids Centaur (112.2 kg/ha), Astra Gold (114.0 kg/ha), Almera (116.8 kg/ha), Sun Spot (118.2 kg/ha), and Marvin (119.7 kg/ha).

The pharmaceutical quality of the phytoraw material obtained from the crop is currently determined by the content of a whole range of biodynamic compounds, which, often at minimal concentrations, are capable of activating and normalizing a significant number of physiological processes in the human body. First of all, these include the following: vitamins D and E (tocopherol), flavonoids, β-carotene, choline, and lecithin. Taking into account the above, we analyzed the chemical composition of the obtained phytoraw material specifically according to the criterion of the content of the indicated biologically active compounds for the experimental variants (Table 5, Figure 4).

The analysis of the results presented allows us to conclude that all variants of ornamental sunflower hybrids meet the requirements for raw material intended for pharmaceutical use according to the criterion of the content of physiologically active compounds. On average, based on the results of three years of research, according to the content in dry petals of male flowers of such a compound as tocopherol (vitamin E), the hybrids Centaur (2.44 mg/100 g) and Atilla (2.37 mg/100 g) were recognized as the leaders; according to flavonoid content – Astra Gold, Atilla, Sun Spot, and Teddy Bear (2.80–2.87%); provitamin A (β-carotene) – the most intensely colored hybrids: Almera and Red Sun (10.07 and 9.67 mg%, respectively). The maximum content in the phytoraw material of such a compound as choline (vitamin B4) was noted by us for the variants of the hybrids Marvin and Lime (270.8 and 277.2 mg/100 g, respectively), and according to the criterion of lecithin content in the product, the hybrids Baver (1.91 mg/100 g) and Teddy Bear (1.88 mg/100 g) were recognized as the leaders of the competitive trial.

We believe that the final criterion determining whether a particular accession corresponds to the ecological conditions of the growing zone is a set of indicators (indices) of ecological plasticity and stability of modern ornamental sunflower hybrids. Only comprehensive evaluation, with mandatory consideration of quantitative and qualitative indicators of productivity and

Table 5. Qualitative parameters of phyto-raw material of decorative sunflower hybrids (average over 2023–2025)

Hybrid	Content in absolutely dry matter				
	Tocopherol (vitamin E), mg/100 g	Flavonoids, %	β-Carotene (provitamin A), mg%	Choline (vitamin B4), mg/100 g	Lecithin, mg/100 g
Almera	2.19	2.55	10.07	252.7	1.53
Astra Gold	2.34	2.87	9.37	229.0	1.69
Atilla	2.37	2.86	9.42	244.0	1.45
Baver	2.22	2.63	9.51	265.5	1.91
Italian White	2.12	2.27	7.70	208.7	1.64
Centaur	2.44	2.39	8.64	224.9	1.62
Lime	1.97	2.31	8.02	270.8	1.56
Marvin	2.30	2.50	9.33	277.2	1.70
Moon Light	2.16	2.77	8.08	245.0	1.83
Red Sun	2.22	2.62	9.67	232.6	1.77
Sun Spot	2.31	2.80	8.23	255.2	1.63
Teddy Bear	2.33	2.80	9.39	262.2	1.88
LSD_{05}	0.09	0.12	0.29	8.33	0.14



Figure 4. Correlation between indicators

ecological tolerance, makes it possible to distinguish and identify, with the highest level of reliability, the variants that correspond to the abiotic and biotic conditions of the agrocenosis, and primarily by the stability of their expression with respect to the analyzed traits of a particular crop hybrid (Lavrys, 2023) (Table 6, Figure 5).

On average over the three years of research, we identified the ornamental sunflower hybrid Teddy Bear as the most ecologically adapted to non-irrigated growing conditions in the Southern Steppe of Ukraine: with an average yield of conditioned phytoraw material of 199 kg/ha, it was characterized by the minimum value of the drought susceptibility index among the other variants of the experiment (DSI = 0.79), while at the same time by the maximum value of the drought tolerance index (TOL = 0.83), the maximum value of the yield stability index (YSI = 0.72), yield index (YI = 108), and stress tolerance index (STI = 0.55). Accordingly, the final coefficients of ecological plasticity and stability (bi

Table 6. Indices of complex ecological tolerance of ornamental sunflower hybrids (average for 2023–2025)

Hybrid	Yield, kg/ha	DSI (drought susceptibility index)	TOL (tolerance index)	YSI (Yield stability index)	YI (yield index)	STI (stress tolerance index)	b_i (indicator plasticity)	Sd_i^2 (stability parameter)
Almera	116.8	1.07	0.51	0.51	62	0.39	0.71	0.00070
Astra Gold	114.0	1.09	0.51	0.52	83	0.37	0.77	0.00065
Atilla	123.0	0.95	0.57	0.59	96	0.46	0.99	0.00069
Baver	177.0	0.81	0.74	0.68	102	0.52	1.05	0.00080
Italian White	126.2	0.94	0.61	0.64	95	0.42	0.94	0.00083
Centaur	112.2	1.22	0.47	0.65	69	0.33	0.62	0.00058
Lime	153.3	0.84	0.70	0.66	101	0.50	1.01	0.00082
Marvin	119.7	1.01	0.55	0.57	77	0.41	0.67	0.00068
Moon Light	141.6	0.85	0.64	0.60	98	0.44	1.00	0.00079
Red Sun	138.7	0.92	0.61	0.63	97	0.40	0.93	0.00077
Sun Spot	118.2	0.97	0.52	0.57	67	0.32	0.60	0.00071
Teddy Bear	198.9	0.79	0.83	0.72	108	0.55	1.09	0.00091

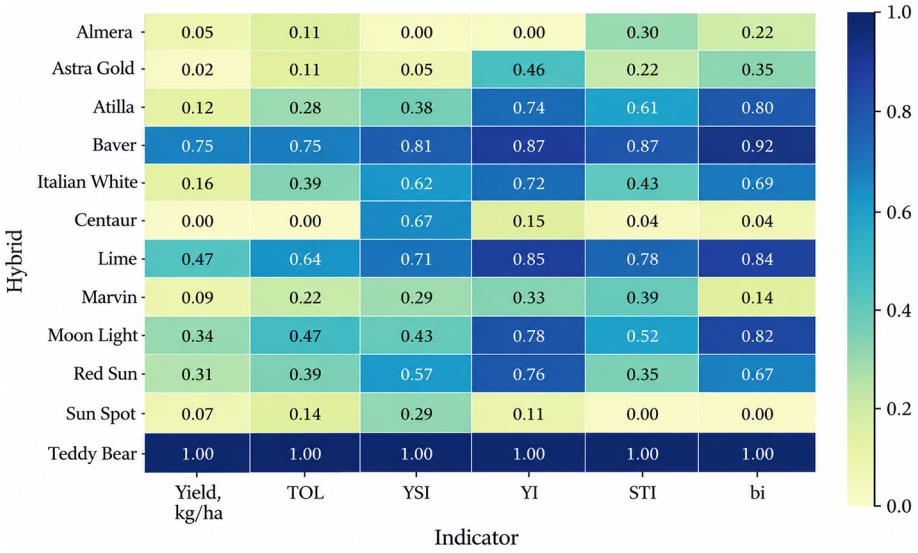

Figure 5. Heat map of normalized indicators of hybrids

and Sdi^2) for the variant of this hybrid were also maximal in the experiment and amounted to 1.09 and 0.00091, respectively. Also, based on the set of the above criteria, we recognized the hybrids Baver and Lime as promising variants, which were insignificantly inferior to the leader of the competitive trial. At the same time, we recognized the ornamental sunflower hybrids Centaur, Astra Gold, and Almera as poorly suitable for cultivation under non-irrigated conditions of the southern-steppe agroclimatic zone for the purpose of obtaining phytoraw material for pharmaceutical use, since their indices of complex ecological tolerance during the study years were characterized by insufficient levels.

DISCUSSION

Our studies showed that ornamental sunflower (*Helianthus annuus ornamentalis*) is a promising niche crop for producing pharmaceutical raw materials under non-irrigated conditions in Ukraine's Southern Steppe. The data obtained agree with the conclusions of other researchers regarding the high pharmacological potential of this crop, which is due to the presence of a broad spectrum of biologically active compounds (Islam et al., 2025; Lavrenko et al., 2025; Zhuikov et al., 2025). In particular, Guo et al. (2017), Adeleke and Babalola (2020), and Barreto et al. (2026) emphasised that sunflower petals and seeds contain phenolic acids, flavonoids, tocopherols and carotenoids, which exhibit antioxidant, anti-inflammatory and antimicrobial effects. Our studies extend these concepts by demonstrating that, specifically, the petals of male ray florets of ornamental hybrids can serve as a concentrated source of tocopherol (up to 2.44 mg/100 g), flavonoids (up to 2.87%), β-carotene (up to 10.07 mg%) and choline, which makes them a valuable raw material for the pharmaceutical industry. This confirms the feasibility of reorienting part of sunflower production from the traditional oilseed direction to the pharmaceutical one, which, as noted earlier, will contribute to unloading crop rotations and improving their ecological state.

A comparative analysis of phenological and biometric indicators revealed substantial differentiation of hybrids in terms of the duration of interphase periods and plant height. The sowing-to-emergence period (6–10 days) and the total growing season (109–124 days) align with literature on the earliness of ornamental sunflower cultivars (Zhuykov et al., 2024). At the same time, the hybrids Baver and Teddy Bear, which were distinguished by the highest plant survival coefficient (0.63–0.64) and the most filled generative part, demonstrated the best adaptation to drought conditions. This agrees with the conclusions of Yeremenko et al. (2018) that modern sunflower hybrids show a pronounced response to agrometeorological conditions, and their ecological plasticity is critically important for stable production in a zone of insufficient moisture (Yeremenko et al., 2018). The low survival coefficient of the hybrids Italian White (0.47) and Sun Spot (0.49), in

our opinion, indicates their high sensitivity to abiotic stressors, which makes them economically risky for cultivation in the region (Yeremenko et al., 2018; Hamayunova et al., 2025).

A key stage of the study was the comprehensive assessment of ecological tolerance and stability of the hybrids using a set of indices (DSI, TOL, YSI, YI, STI) and parameters of plasticity and stability according to the Eberhart-Russell model (Eberhart, Russell, 1966). The use of this methodology for assessing the adaptability of sunflower in the conditions of the Ukrainian Steppe was previously tested in the works of Yeremenko et al. (2018) and other researchers, who confirmed its effectiveness for identifying genotypes with a broad reaction norm (Darvishzadeh et al., 2011). Our results showed that the Teddy Bear hybrid, despite its high plasticity coefficient (bi = 1.09), which indicates its ability to use favourable conditions effectively, was at the same time characterised by the minimum value of the drought susceptibility index (DSI = 0.79) and the highest values of yield stability (YSI = 0.72) and stress tolerance (STI = 0.55). This agrees with the provisions of Bouslama and Schapaugh (1984) and Gavuzzi et al. (1997) that high YSI and YI values are reliable criteria for selecting genotypes suitable for cultivation under moisture deficit conditions. The Baver and Lime hybrids also entered the group of promising genotypes due to a balanced combination of high yield (177.0 and 153.3 kg/ha, respectively) and satisfactory stability indices. Instead, the Centaur, Astra Gold and Almera hybrids proved to be poorly suitable for drought conditions, which is confirmed by high DSI and low STI and YSI values.

The analysis of the qualitative composition of the phyto-raw material showed that all studied hybrids meet the requirements for pharmaceutical raw material; however, they have different specificity of accumulation of biologically active substances. In particular, the leaders in tocopherol content were Centaur and Atilla; in flavonoid content, Astra Gold, Atilla, Sun Spot and Teddy Bear; in β-carotene content, Almera and Red Sun; in choline content, Marvin and Lime; and in lecithin content, Baver and Teddy Bear. Such differentiation allows targeted selection of hybrids depending on the needs of the pharmaceutical industry, which is an important advantage for creating specialised raw-material zones (Guo et al., 2017; Adeleke and Babalola, 2020; Barreto et al., 2026). At the same time, it should be noted that our data on the content of biologically active compounds agree with the results of other studies confirming the presence of phenolic acids, flavonoids, and terpenes in different parts of Helianthus annuus and their potential as a source of antioxidant and anti-inflammatory agents (Zhuykov et al., 2024).

Summarising, it should be emphasised that the reorientation of part of the sown areas to ornamental sunflower is not only an environmentally expedient step for unloading crop rotations but also an economically promising direction. The combination of high yield of standard-quality phyto-raw material (up to 198.9 kg/ha in the Teddy Bear hybrid), rich content of biologically active substances, and high ecological plasticity makes the Teddy Bear, Baver, and Lime hybrids priority ones for introduction into organic production of pharmaceutical raw material under the conditions of the Southern Steppe of Ukraine. Further studies should be aimed at optimising sowing rates and elements of biologised cultivation technology specifically for these promising genotypes, as well as at an in-depth study of the pharmacological properties of the obtained extracts. A promising direction is also the use of vegetation indices, in particular NDVI, for monitoring crop condition and predicting the productivity of niche crops.

CONCLUSIONS

Despite the fact that the nomenclature of modern ornamental sunflower hybrids includes more than 15 accessions, far from all of them are suitable for cultivation under non-irrigated conditions of the Southern Steppe for the purpose of obtaining phytoraw material for pharmaceutical use. An analysis of the phenological data in the experiment allows us to conclude that, according to the duration of the “sowing-emergence” interphase period, the hybrids Teddy Bear and Centaur were recognized as the leaders in the experiment, with their seedlings emerging on the 6th day after sowing. The maximum duration of active flowering of the heads was recorded for the variant of the hybrid Baver, whose plants flowered for 54 days; the variant of the hybrid Marvin (50 days) and Teddy Bear (49 days, respectively) were somewhat inferior to it. The latter variant was also recognized in the experiment as being characterized by the longest growing season, at the level of 124 days. All hybrids were differentiated

by us into the following groups according to plant habit: short-stemmed (130–140 cm) - Almera, Lime, Teddy Bear; medium-stemmed (140–150 cm) - Astra Gold, Baver, Italian White, Moon Light; tall (above 150 cm) - Atilla, Centaur, Marvin, Red Sun, and Sun Spot.

The maximum plant survival rate in the experiment was recorded by us for the variants of the hybrids Baver and Teddy Bear (0.63–0.64), while the minimum was recorded for the variants of the hybrids Italian White and Sun Spot, in the sowings of which we noted plant survival during the growing season at the level of 47–49%.

The maximum yield of male petals from one inflorescence in the air-dry state was noted in the experiment for two variants of the crop hybrids - Baver and Teddy Bear: on average over the study years it amounted to 1.6 g; the hybrids Atilla and Red Sun were somewhat inferior to them (1.3 g, respectively). The absolute majority of the other hybrids were characterized by a petal mass from one inflorescence at the level of 1.0 g or less. The final parameter - the productivity of one plant, which took into account simultaneously both the number of inflorescences per plant and the mass of air-dry petals from each of them - had the following gradation: the leader in the experiment was recognized as the hybrid Teddy Bear (5.2 g of conditioned phytoraw material per plant), in second place the hybrid Baver with a value of 4.8 g, in third - the hybrid Lime (3.6 g).

On average over the study years, the hybrids characterized by the maximum yield of conditioned phytoraw material for pharmaceutical purposes (petals of male ligulate flowers in the air-dry state) were recognized by us as the following variants: Teddy Bear – 198.9 kg/ha, Baver – 177.0 kg/ha, and Lime – 153.3 kg/ha, respectively. The hybrids Moon Light and Red Sun (141.6 and 138.7 kg/ha, respectively) were recognized by us as promising according to the productivity parameter. The ornamental sunflower hybrid Teddy Bear was recognized by us as the most ecologically adapted to non-irrigated growing conditions in the Southern Steppe of Ukraine; the variants of the hybrids Baver and Lime were recognized as promising, as they were insignificantly inferior to the leader of the competitive trial; and Centaur, Astra Gold, and Almera were recognized as poorly suitable, since their indices of complex ecological tolerance during the study years were characterized by insufficient levels.

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