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FUTURE DIRECTIONS FOR USE OF BIOLOGICAL AND BIORATIONAL HERBICIDES IN RUSSIA

(review)

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Abstract

The emergence of weed populations resistant to chemical herbicides leads to a widespread decrease in the effectiveness of the chemical control. This fact, along with the currently increasing consumer demand for organic food, leads to an awareness of the need to develop research on the development of biological means of protecting crops from weeds. Despite the fact that biological (BLH) and biorational herbicides (BRH) are being introduced in the market of weed control products in the United States, Canada, China and South Africa, no such products has been registered in the Russian Federation to date. At the same time, the development of research on the development of environmentally friendly means of weed control allows to count on a change in the existing situation in the foreseeable future (A.O. Berestetskiy, 2017; M. Triolet et al., 2020). The purpose of this literature review was to analyze the current range of chemical herbicides allowed for use in Russia in order to identify market niches that BLH and BRH may occupy in the near future. To assess the prospects of these products, first of all, the spectrum of their action was taken into account, due to the species specificity of plant pathogens, which is significantly narrower than the activity spectrum of chemical herbicides (A. Berestetsky et al., 2018; A. Berestetsky, 2021). The analysis was based on a list of pest organisms that are particularly dangerous for crops prepared by the All-Russian Research Institute for Plant Protection (2013), in which the following types of weeds were indicated: perennial sowthistle (*Sonchus arvensis* L.), Canada thistle (*Cirsium setosum* (Willd.) Bess.), field bindweed (*Convolvulus arvensis* L.), couch grass (*Elytrigia repens* (L.) Nevski), and wild oat (*Avena fatua* L.). The list was supplemented with two quarantine weeds, common ragweed (*Ambrosia artemisiifolia* L.) and Russian knapweed (*Acroptilon repens* DC.), which are limited in the territory of the Russian Federation, but are problematic for a number of regions. These types of weeds have different degrees of harmfulness in different crops (A.M. Shpanev, 2011). The analysis involved the most significant agricultural crops from the point of view of the structure of the arable land of the Russian Federation. The use of BLH and BRH seems most promising in orchards and vineyards, where, due to the exclusion of glyphosate-based herbicides, only gufosinate-ammonium is allowed for use (A.S. Golubev et al., 2018; 2019). In addition, BLH and BRH, used in combination with some herbicides, would increase the effectiveness of weed control and the duration of the protective effect. The risks of using BLH and BRH in orchards and vineyards do not look significant due to the relative isolation of these agroecosystems. Forage crops and greenhouse vegetables do not have much potential as niches for the use of BLH and BRH, forage crops due to low economic returns, and vegetables in greenhouses due to the peculiarities of their cultivation technology. The use of BLH and BRH in fields intended for sowing agricultural crops in the autumn period and in fallow fields looks promising. In the conditions of crop rotations, BLH and BRH can be applicable against perennial root-sprouting weeds and Russian knapweed during the growing season of soybeans, sunflower, and potatoes. For the last two crops, the use of BLH and BRH against common ragweed looks promising as well. It will be possible to occupy a niche associated with the destruction of grass weeds (such as couch grass or wild oat), in the conditions of the existing range of chemical herbicides, only for the suppression of resistant weed populations.

Keywords: bioherbicides, cereals, corn, soybean, sunflower, potato, orchard, *Sonchus arvensis*, *Cirsium setosum*, *Convolvulus arvensis*, *Elytrigia repens*, *Avena fatua*, *Ambrosia artemisiifolia*, *Acroptilon repens*

Weeds represent a traditional challenge to cultivation of agricultural, medicinal, and ornamental crops. The main control measures include the use of chemical herbicides and, to a lesser extent, tillage. Due to a decrease in the effectiveness of the chemical control owing to the appearance of herbicide-resistant weeds, on the one hand, and owing to an increase in the share of consumption of organic food, on the other hand, there is a need to reduce the use of chemicals in the agricultural production. At the same time, for the control of weeds, certain hopes rest on the biological (BLH) and biorational (BRH) herbicides [1, 2].

There are many examples of widespread and commercially successful use of entomophages, microbiological preparations, and natural compounds to combat pathogens and phytophages. As practice shows, the effectiveness of BLH and BRH, as a rule, is significantly lower than chemical ones [3, 4]. In this regard, they are of limited use: in greenhouses, in organic farming, and in public places where the use of the chemical control methods is prohibited.

The purpose of this literature review was to analyze the current range of chemical herbicides allowed for use in Russia in order to identify market niches that BLH and BRH may occupy in the near future.

Bioherbicides are preparations used for weed control, consisting of live microorganisms and auxiliary components (surfactants, adjuvants, preservatives, water-retaining additives, and inert fillers). Since phytopathogenic fungi are mostly considered as active components of bioherbicides (BHB), preparations based on them are isolated into a separate group and called mycoherbicides (MHB). Plant or microbial extracts with phytotoxic properties, purified or semi-purified natural phytotoxins are classified as biorational chemical herbicides (BRH) [1].

The use of BHB is aimed at causing local epiphytotics in populations of unwanted plants and, as a consequence, reducing their competitiveness. BHB are designed for regular use, but their effect can be prolonged for several seasons. BHB are selective microbiological preparations suppressing one or several types of weeds. Some BHBs contain weakly specialized phytopathogens found both on target weeds and on cultivated plants. Such pathogens can be used in special situations when susceptible crops are not sown or are not included in the crop rotation where weed biocontrol is planned [5-7].

Herbicide preparations based on natural phytotoxins (biorational herbicides) have certain advantages over BHB: clear mechanisms of action and quality control, significantly less dependence of efficiency on external factors. Phytotoxic compounds are predominantly secondary metabolites of plants (allelopathy effect) and microorganisms (factors of plant pathogenicity or colonization), killing plant cells in small concentrations. In addition, some primary metabolites have phytotoxic properties: a number of amino acids, some organic and fatty acids [8, 9].

The existing biorational plant protection products, including BRH, can be conditionally divided into four groups: microbial preparations of toxin action; coarse extracts of plant or microbial origin; individual natural compounds (or mixtures thereof) of various degrees of purification; synthetic analogs of natural compounds [10]. The latter, strictly speaking, do not belong to the natural ones, therefore, in this review we are not considering chemical herbicides based on them.

The first group includes such preparations as Bioprotec Herbicide™ (AEF Global, Inc., Canada) containing lactobacilli, which form phytotoxic lactic and citric acids to inhibit the growth of clover on lawns [11]. For the control of the parasitic weed *Striga hermonthica* (Delile) Benth., a bioherbicide based on *Fusarium oxysporum*, a superproducer of tyrosine, an amino acid that is able to inhibit the development of striga was developed in the United States [12]. MHB based on *Phoma macrostoma* fungus (Evologic Technologies GmbH, Austria) acts due to phytotoxins from the group of macrooxazoles [13, 14].

The next group of BRH includes essential oils, plant extracts, green manures, and food waste [15]. For instance, in the United States, corn gluten is used as BRH, the decomposition of which produces phytotoxic peptides [16]. Milled green mass of mustard and soy flour (application rate, respectively, about 1 and 4 t/ha) were effective for suppressing weeds in the crops of spinach *Spinacia oleracea* L. and broccoli *Brassica oleracea* L. var. *italica* in organic farming [17].

An extract from the legume plant *Canavalia ensiformis* (L.) DC showed high herbicidal activity in suppression of ivy *Ipomoea grandifolia* (Dammer) O'Donell and *Commelina benghalensis* L. in soybean crops [18]. Essential oils of about 20 plant species used to control various types of weeds were reviewed by R. Raveau et al. [19]. It seems interesting to use essential oils of ragweed weeds having phytotoxic properties [20]. Phenolic substances from *Ludwigia hyssopifolia* (G. Don) Exell provided significant suppression of shoot growth and biomass accumulation in *Amaranthus spinosus* L., *Dactyloctenium aegyptium* L., and *Cyperus iria* L. [21].

Several commercial and trial BRHs are known from the third group of biorational plant protection products. Acetic acid is used to control weeds on small gardens in the United States [16]. A herbicide mixture based on acetic and citric acids could be effective [22]. The phytotoxic glycoside tricolorin A has been isolated from the biomass of *Ipomoea tricolor* Cav., which Mexican farmers use as a cover crop on sugarcane to suppress weeds. This phytotoxin at a concentration of 60 μM acts as a nonselective inhibitor of seed germination and plant shoot growth and can be considered as an alternative to glyphosate [23]. Marrone BioInnovations (USA) has developed Opportune® preparation, the active ingredient of which is the bacterial phytotoxin takstomin A. Belchim Crop Protection (Belgium) offers BRH Katoun® Gold based on pelargonic acid for use in the organic farming [11]. Tenuazonic acid, produced by some fungi of *Alternaria* genus, is patented by Chinese scientists and is being studied as a natural herbicide with an original mechanism of action. Its chemical synthesis has been developed and the possibility of practical application in the field has been shown [24].

According to the literature analysis, new herbicidal compounds of natural origin are actively being sought in the world [25]. Officers of Dow AgroSciences LLC (USA) have identified a number of microbial phytotoxins which are perspective for creation of new BRHs: macrocidin [26], cinnacidin [27], albucidin [28], and mevalocidin [29]. Cordycepin (a metabolite of the fungus *Cordyceps militaris* (L.) Fr.) at a concentration of 0.04 mg/ml inhibited the growth of radish roots several times stronger than benzoic acid and glyphosate [30].

The natural compound plumbagin (5-hydroxy-2-methyl-1,4-naphthoquinone) was isolated from the leaves of *Plumbago auriculata* (Lam.) Spach, which was effective in field conditions against a number of monocotyledonous and dicotyledonous weeds [31]. Ailantone from *Ailanthus altissima* (Mill.) Swingle is perspective for the development of a new natural herbicide [32]. Asteric acid (one of the secondary metabolites of fungus *Aspergillus terreus* Thom) is a highly active dihydroxy acid dehydratase inhibitor and an effective post-emergence herbicide [33].

To increase the efficiency of weed control, various chemical herbicides, BRH and BLH can be used together to enhance their action. [34]. For a long time, mixtures of natural products, such as acetic acid, lemon extract and clover oil, have been used for organic farming and on lawns [35]. A composition increasing the effectiveness of glyphosate (0.8-1.2 l/ha), which includes a mixture of L-

2-amino-2-methyl-mercaptobutyric acid, L-α-diaminocaproic acid, and L-β-phenyl-α-aminopropionic acid (about 10 g/ha at a ratio of components 2:1:1) and ammonium nitrate (2 kg/ha) has been developed. An increase in the efficiency of glyphosate is achieved by more active absorption of the herbicide by weeds, which makes it possible to reduce the rate of its consumption. Microfield and field tests have shown the possibility of reducing the rates of glyphosate application by about 2 times when combined with a mixture of succinic and malic acids at a concentration of 10 - 11 M [36]. The mixture of manuka *Leptospermum scoparium* J.R. Forst. & G. Forst. essential oil and pelargonic acid was effective against three weed species (*Lolium rigidum* Gaud., *Avena sterilis* L., and *Galium aparine* L.) [37].

In the Russian Federation, there are no registered BLH and BRH, and there is little research in this regard. In particular, producers of herbicidal compounds (pheosferide A, stagonolide A, and herbarumina I) — strains of the fungi *Paraphoma sp.* and *Stagonospora cirsii* have been patented. Methods for their application have been developed, but there are no clear ideas about the prospects for their use; toxicology and methods of pilot production for field trials are poorly studied [38].

The effectiveness of BLH and BRH is lower than that of chemical herbicides, the area of treatment cannot be large, and the shelf life of such preparations is limited. However, they can be used in organic farming or as a component of an integrated control of particularly harmful weeds.

The registration stage following the creation of the preparation requires significant financial costs. Typically, such expenses are available to large chemical companies, whose marketing departments calculate an approximate return on the cost of bringing the bioherbicide to the market. At the same time, even considerable investments in registration of a preparation do not always repay by its high activity in the field [4].

In our opinion, the most important stage in planning a strategy for bringing scientific developments of biological and biorational herbicides to the end user should be a clear identification of market niches for their economically justified use, as well as an assessment of market prospects, taking into account the existing range of chemical herbicides for protection of major crops. It should be noted that this approach is especially significant in Russia, where no such preparation has yet been registered.

To assess the market prospects of BLH, it is important to take into account the spectrum of their action, due to the species specificity of phytopathogens. It requires a list of weed species, the use of biopreparations against which may be appropriate. It should also be noted that BRH based on organic acids, fats, and oils obtained from plants are less effective than chemical agents and require significant amounts of application, which complicates the use of BRH in industrial plant growing [39].

In 2013, All-Russian Research Institute for Plant Protection has prepared a list of pest organisms that are particularly dangerous for crops, in which the following types of weeds were indicated: perennial sowthistle (*Sonchus arvensis* L.), Canada thistle (*Cirsium setosum* (Willd.) Bess.), field bindweed (*Convolvulus arvensis* L.), couch grass (*Elytrigia repens* (L.) Nevski), and wild oat (*Avena fatua* L.) [40]. This list, in our opinion, can be taken as a basis and supplemented with two quarantine weeds, common ragweed (*Ambrosia artemisiifolia* L.) and Russian knapweed (*Acroptilon repens* DC.), which are limited in the territory of the Russian Federation, but are problematic for a number of regions [41]. These types of weeds have different degrees of harmfulness in different crops.

An analysis of the structure of the sown areas of the Russian Federation makes it possible to compile a list of the most significant agricultural crops. In

2019, cereals and legumes are 58.4% of the total sown area; industrial crops occupied 19.9%, fodder crops 19.3% [42]. It can be assumed that the latter group does not have significant potential as a niche for the use of microherbicides due to the low economic return. Greenhouse vegetables also do not look promising due to the peculiarities of their cultivation technology.

We will consider grain crops in aggregate, since most herbicides are allowed for use simultaneously on wheat (winter and spring), barley (spring and winter), and oats. As individual crops, we will take the most common: soybeans from the group of legumes, whose share is 2.7% of the total amount of all sown areas, corn (3.2%), sunflower (10.7%), and potatoes (1.6%) [42]. To systematize the approach to the analysis, we further described the type of weed plant, the degree of its threat to the crop, the range of herbicides that can effectively control the number of the object in the crops, and possible alternative solutions.

Perennial sowthistle, Canada thistle, and field bindweed belong to the group of perennial root weeds. The presence of Canada thistle and sowthistle among the dominant species is typical for most regions of Russia, whilst the field bindweed is more common in the middle and southern regions [43]. According to the research of A.M. Shpaneva (2011-2013), these perennial weeds in their harmfulness significantly exceed annual weeds [44-46].

Usually they are fought with the introduction of general exterminating glyphosate-based herbicides: Roundup Max, WS (450 g/l glyphosate/isopropylamine salt), Sprut Extra, WS 540 g/l glyphosate/potassium salt), Kileo, WSC (240 g/l glyphosate/isoprolamine salt + 160 g/l 2,4-D/3-alkylaminopropyl dimethylamine salt), etc. However, the use of these preparations, as a rule, is possible only in fallow fields and in fields intended for sowing or planting various crops in late summer or in autumn in the post-harvest period [47]. On individual crops (sunflower, soybeans), the preparations can be applied 2-5 days before sowing, on corn — 2 weeks before sowing, on potatoes — 2-5 days before the emergence of crop shoots.

Despite the high efficiency of general exterminating herbicides in the fight against perennial root-sap weeds, such treatments are becoming a preventive measure, which does not fully correspond to modern ideas about the ecological development of plant protection. In addition, in view of possible restrictions or even a ban on the use of glyphosate in our country [48], it makes sense to focus on drugs to combat perennial root weeds during the growing season.

A significant number of such preparations are among herbicides for protecting grain crops. The highly specialized herbicides against sowthistle and Canada thistle include preparations based on clopyralid, such as Lontrel-300, WS (300 g/l), Hacker, WSG (750 g/kg), Lontrel grand, WDG (750 g/kg); against field bindweed — the preparations based on fluroxipir: Demeter, EC (350 g/l), Starane Premium 330, EC (333 g/l). Preparations of a wider spectrum of action have been developed on the basis of proven and well-reputed active ingredients, such as 2,4-D acid esters — Esteron 600, EC (600 g/l), Drotik, CSC (400 g/l), Estet, EC (600 g/l); sulfonylureas — Laren Pro, WDG (600 g/kg metsulfuron-methyl), Tribun, DFC (750 g/kg tribenuron methyl), etc. In addition, there is a significant number of combined preparations that have high activity against perennial root-sapling weeds: Prima, SE (300 g/l 2,4-D/complex 2-ethylhexyl ether/ + 6.25 g/l florasulam), Bomb, WDG (563 g kg tribenuron methyl + 187 g/kg florasulam), Unico, CSC (100 g/l fluroxipir + 2.5 g/l florasulam), etc. [49].

The same preparations are often used on corn crops as on cereals [50]. Of the complex action herbicides specific for corn, one could use as an example the herbicide Modern, EC (412 g/l 2,4-D/complex 2-ethylhexyl ether/ + 80 g/l nicosulfuron + 8 g/l florasulam).

The number of herbicides for the control of perennial dicotyledonous weeds on soybeans, sunflowers and potatoes is significantly less. If we consider soybeans, herbicides Harmony Classic, WDG (187.5 g/kg thifensulfuron methyl + 187.5 g/kg chlorimuron-ethyl) and Fabian, WDG (450 g / kg imazethapyr + 150 g/kg chlorimuron ethyl). It is possible to use chemical preparations to suppress Canada thistle and thistle species on sunflower crops during the growing season of the crop only on special hybrids resistant to sulfonylureas, for example, tribenuron methyl [51]. For these purposes, Express, WDG (750 g/kg tribenuron methyl), Sanflo, WDG (750 g/kg), Prometheus, WDG (750 g/kg) are used. During the growing season of potatoes, some activity against perennial root-sprouting weeds is observed when using preparations based on rimsulfuron — Titus, DFC (250 g/kg), Cassius, WSP (250 g/kg), Escudo, WDG (500 g/kg), although it is difficult to solve the problem by limiting the use of only these preparations [52].

In our opinion, it is the niche of the fight against perennial dicotyledonous weeds that looks the most attractive for the use of bioherbicides. On the one hand, this is due to the existing assortment of chemical herbicides (and the possible exclusion of glyphosate from the number of preparations permitted for use), on the other hand, by the very number of pathogens of perennial root weeds. So, only for the fight against the field thistle *Phoma destructiva*, *Phoma hedericola*, *Phoma exigua*, *Puccinia punctiformis*, *Mycelia sterilia*, *Phomopsis cirsii*, *Sclerotinia sclerotiorum*, *Alternaria cirsinoxia*, *Stagonospora cirsii*, *Septoria cirsii*, and *Phyllosticta cirsii* were considered [53-55].

As of January 1, 2019, Russian centaury was found in 19 constituent entities of the Russian Federation, and the area of the established quarantine phytosanitary zones exceeded 1,885,590 hectares (56].

As a rule, the fight against the Russian centaury is most effective in fallow fields and fields intended for sowing grain crops. The following preparations are used: General Secretary, WSG (88.5 g/l dicamba + 88.5 g/l picloram + 177 g/l clopyralid), Gorgon, WSC (350 g/l MCA acid + 150 g/l picloram) [57]. During the growing season of the crop, you can use Octymet, EC (500 g/l 2,4-D acid + 5.5 g/l metsulfuron methyl) or Lancelot 450, WDG (300 g/kg aminopyralide + 150 g/kg florasulam).

The range of herbicides in this direction is small, and since preparations for the control of the Russian centaury usually have strict limitations on crop rotation [58], the development of alternative, including biological, means of control is potentially attractive. The fact that there are no herbicides approved for use on vegetative plants of corn, soybeans, sunflower, and potatoes to control the Russian centaury makes this area even more urgent.

At the end of the 20th century, attempts were made to use nematodes from the genus *Subanguina picridis* Kirj & Ivan as biogrebicides to control the Russian centaury. [59]. At beginning of the 21st century, it was proposed to use the allelopathic effect of essential oils of eucalyptus, Lawson's cypress, rosemary and white cedar for this purpose [60].

As of January 1, 2019, ragweed was found in 31 constituent entities of the Russian Federation, the area of the established quarantine zones exceeded 7,356,593 hectares [56]. It should be noted that ragweed not only worsens the growing conditions of cultivated plants, reducing their productivity, but also causes allergic reactions [61].

As in the case of perennial dicotyledonous weeds, herbicides based on clopyralid can be used to control this species on crops of grain crops, for example, Agron, WS (300 g/l), Agron Grand, WDG (750 g/kg), and also using the preparations with a wider spectrum of action, including the combined ones — Primadonna, SE (200 g/l 2,4-D acid + 3.7 g/l florasulam), Ballerina, SE (410 g/l

2.4-D acid + 7.4 g/l florasulam) [62]. These combined herbicides can also be applied to corn crops. In addition, maize crops use specific herbicides MaysTer, WDG (300 g/kg foramsulfuron + 10 g/kg iodosulfuron methyl sodium + 300 g/kg antidote isoxadifen ethyl) and MaysTer Power, OC (31.5 g/l foramsulfuron + 1 g/l iodosulfuron methyl sodium + 10 g/l thiencarbazone methyl + 15 g/l cyprosulfamide antidote) [63].

Soy is a leguminous plant and exhibits natural resistance to herbicides of the imidazolinone group, which can effectively destroy the ragweed plants. The examples of such preparations include Pulsar, WS (40 g/l imazamox) and Pivot, WC (100 g/l imazetapir). In addition, in the fight against this harmful object on soybeans, bentazone based herbicides — Bazagran, WS (480 g/l), Corsair, WSC (480 g/l), Benito, CSC (300 g/l) are successfully used, as well as combined drugs, for example Corum, WSC (480 g/l bentazone + 22.4 g/l imazamox) [64].

When cultivating sunflower hybrids that are resistant to imidazolinones, the introduction of herbicides of this group makes it possible to effectively destroy ragweed plants. Examples of such preparations include Euro-Lightning, WSC (33 g/l imazamox + 15 g/l imazapir), Pulsar, BP (40 g/l imazamox), Tapir Hybrid, OC (50 g/l imazethapyr + 20 g/l imazapir) [65].

Since clopyralid, bentazone and imidazolinones are not recommended for use in potato plantings, there are no highly effective means of combating ragweed during the growing season of this crop.

It should be noted that due to the significant stock of ragweed seeds in the soil, the second and sometimes the third wave of emergence of this weed plant can be observed in the agricultural crops. During this period, agrotechnical and chemical weed control is challenging due to the peculiarities of the biology of cultivated plants. As a result, ragweed plants go through the entire biological cycle of development, including seed maturation, which leads to their even greater distribution [66]. Therefore, despite the wide range of herbicides to control this object, biological products can be included in the system of protective measures against ragweed in addition to the chemical agents.

A promising direction is the use of essential oils *Nepeta rtanjensis* Dikli and Milojevi, as well as *N. cataria* L. [67]. Application of biofumigation based on allopathic mechanisms of the relationship between mustard *Brassica juncea* (L.) Czern. and this weed, allows reducing the number of seedlings of the latter [68].

Couch grass is one of the most vicious weeds, found everywhere. In the arid conditions of the southern steppes, semi-deserts and deserts, it loses its importance as a weed [69]. As a rule, it is not widespread in crops of grain crops, and its appearance in them indicates a low efficiency in agriculture.

In corn crops, couch grass in some regions (for example, in the Central region of the Non-chernozem zone) is quite common [70]. Weed control is carried out using rimsulfuron-based herbicides — Titus, DFC (250 g/kg), Cassius, WSP (250 g/kg); nicosulfuron — Nissin, SC (40 g/l), Ikanos, OC (40 g/l), Innovate, SC (240 g/l), DUBLON, SK (40 g/l) or combined preparations — Cordus, WDG (500 g/kg nicosulfuron + 250 g/kg rimsulfuron), Elumis, OC (75 g/l meso-trione + 30 g/l nicosulfuron) [71].

To protect soybean, sunflower and potato plantings, preparations based on fluazifop-P-butyl — Fuzilad Forte, EC (150 g/l), Fuzilad Super, EC (125 g/l); quizalofop-P-tefurila — Bagira, EC (40 g/l), Panther, EC (40 g/l), Heeler, EC (40 g/l); cellularhodima — Select, EC (120 g/l), Centurion, EC (240 g/l) could be used. At the same time, in addition to those listed, rimsulfuron based herbicides are used on potatoes [72].

According to the available data, most biological agents for suppressing couch grass are still too expensive and are associated with high labor costs [73], therefore, there are few specific developments in this direction.

Common wild oats need a warm climate and dry soils. Its main habitat and harm zones are located in the southeast of the European part of Russia and the Southern Urals, where wild oats dominate in grain crops [43].

The range of wild oat herbicides recommended for these crops is extremely wide. It includes preparations based on fenoxaprop-P-ethyl — Puma Super 7.5, OWE (69 g l + 75 g/l of the antidote mefenpyr-diethyl), Ocelot, EC (100 g/l + 27 g/l of the antidote cloquintoset-mexil); clodinafoppropargyl — Topik, EC (80 g/l + 20 g/l of cloquintoset-mexil antidote); kick-sadena — Axial 50, EC (50 g/l + 12.5 g/l of cloquintoset-mexil antidote); flucarbazone sodium — Everest, WDG (700 g/kg), etc. With a mixed type of weediness, preparations are used for the complex suppression of dicotyledonous weeds and annual cereal weeds Alistair Grand, OC (6 g/l meso-sulfuron-methyl + 4.5 g/l iodosulfuron-methyl-sodium + 180 g/l diflufenican + 27 g/l mefenpyr diethyl), Ocelot Cross, EC (290 g/l MCA acid/2 ethylhexyl ether/+ 49 g/l fenoxaprop-P-ethyl + 15 g/l cloquintoset-mexil) [74].

To protect crops of corn, soybeans, sunflowers and potato plantings from annual cereal weeds, which include wild oats, the same preparations as for fighting wheatgrass are used. In addition to the listed funds, on planting potatoes, you can use herbicides based on metribuzin — Zenkor Ultra, SC [600 g/l), Lazurit, SP [700 g/kg), Soil, WDG (700 g/kg) [75].

It should be noted that the emergence of resistant populations of common wild oat might become an urgent problem in the future. Reports on the resistance of wild oats to fenoxaprop-P-ethyl were received from the Altai Territory [76]. The development of bioherbicides to combat resistant forms may be promising, despite the wide range of chemical herbicides.

There are no BLH and BRH against wild oats, although studies have been conducted abroad for a long time to identify and use its various pathogens, as well as searches for natural compounds that inhibit its growth. In particular, the mycobiota of wild oat seeds was studied in order to reduce their viability [77, 78], a rust fungus was tested under field conditions [79], the conditions of infection by *Drechslera avenae* and the range of plants susceptible to it were studied [80, 81]. In Australia, where wild oats turned out to be an invasive species, *D. avenae* was proposed to combat it, but in Russia this fungus serves as the causative agent of oat disease and therefore can hardly be used where this crop is grown. At the same time, a nonselective phytotoxin pyrenoforol A was isolated from the culture of *D. avenae*, which has herbicidal potential for combating wild oats and other weeds [82-84]. It has also been proposed to use eucalyptus essential oils [85, 86], bioactive ragweed sesquiterpenes [87], and even papaya extract [*Carica papaya* L.) [88].

Due to its special relevance [danger to humans and rapid spread), we cannot ignore the Sosnovsky hogweed (*Heracleum sosnowskyi* Manden.), which has a limited distribution on agricultural lands due to the complex of agricultural activities carried out on them. As a rule, the finding of Sosnovsky hogweed specimens on arable land indicates a very low level of farming. The main habitats of this species are non-agricultural lands, pastures and grasslands, ditches and roadsides, as well as areas occupied by forest vegetation.

The range of herbicides approved for use against Sosnovsky's hogweed on non-agricultural lands includes preparations based on glyphosate — Tornado, WS (360 g/l), Total, WS (360 g/l); sulfometuron-methyl — Ankor-85, WDG (750 g/kg); metsulfuron-methyl — Zinger, SP [600 g/kg); imazapira — Shkval, WC (250 g l), Arbonal, WC (250 g/l). Some of the preparations are combinations of the indicated active substances — AtronPro, WDG (250 g/kg imazapir + 75 g/kg sulfometuron-methyl), Gorgon, WSC (350 g/l MCA acid + 150 g/l picloram), Grunge, WDG

(525 g/kg glyphosate (potassium salt) + 105 g/kg sulfometuron-methyl + 20 g/kg chlorsulfuron) and General Secretary, WSG (88.5 g/l dicamba + 88.5 g l picloram + 177 g/l clopyralid). To combat Sosnovsky's hogweed on hayfields and pastures, it is allowed dicamba-based herbicides to be used, for example Banvela, WS (480 g/l), Dianata, WS (480 g/l).

On the one hand, a wide range of chemical herbicides on the market for the control of Sosnovsky's hogweed does not open up wide opportunities for the introduction of bioherbicides into it. On the other hand, a potentially interesting niche for the use of biological products can be their joint use with selective sulfonylureas or dicamba based herbicides. The fact is that one of the main conditions for achieving a long-term effect in the destruction of Sosnovsky hogweed is to prevent re-contamination of areas cleared of weeds. For these purposes, either "replacement plantings" in the form of lawn grasses are used, or the complete destruction of dicotyledonous weeds for the formation of "sod" by means of herbicides selective for cereals, which can potentially be supplemented with biological products. It should be noted, that research in this direction should include the study of the compatibility of sulfonylureas and dicamba with producers of bioherbicides.

An analysis of niches potentially attractive for the introduction of biological products in the agricultural production would be incomplete without mentioning orchards and vineyards. For weed control purposes, only general exterminating preparations based on two active substances are allowed here — glyphosate (in the form of salts) and ammonium glufosinate [89]. Currently, the use of preparations based on glyphosate in our country is significantly limited and the niche of operational means of weed control in orchards and vineyards is vacant (48]. It could be occupied by bioherbicides, which would be especially in demand in the context of combating all the problematic species of weeds indicated in the review, and especially with perennial species (it is known that favorable conditions for the growth and development of knapweed are formed in gardens and vineyards) [90].

Another advantage of using bioherbicides in orchards and vineyards is that they can be applied after the addition of glyphosate. With such technologies, a more prolonged action of the treatment is observed [91]. It is also possible to combine bioherbicides with chemicals, which increases the effectiveness of weed control [92].

An important advantage of bioherbicides in gardens is the ability to protect non-target objects from the negative effects of BLH in the long term. Unlike chemical herbicides, which have been widely used in production for more than half a century, the consequences of the use of bioherbicides can only be predicted empirically. This causes serious concern of scientists, since there are cases of unsuccessful introduction of such preparations [93-95].

Taking into account the possible long-term consequences of the use of bioherbicides, the sphere of a relatively closed agroecosystem of the garden looks most preferable for an attempt at the first approbation of such preparations in agricultural production. The second stage in the introduction of bioherbicides into production can be their inclusion in crop rotation systems in the fields intended for sowing agricultural crops in autumn. In this case, several months will pass from the moment of application of the preparations to sowing the crops. Subject to the successful completion of the first two stages, bioherbicides can be used in fallow fields. The final stage will be their application on sowing and planting of crops.

In conclusion, we give a list of the preparations mentioned in this review:

Preparation	Producer, country
Roundup Max, WS	Monsanto Europe S.A., Belgium
Sprut Extra, WS	AO Shchelkovo Agrokhim, Russia
Kileo, WSC	Nufarm GmbH & Co KG, Austria
Lontrel-300, WS	Dow AgroSciences Vertriebsgesellschaft m.b.H, Austria
Hacker, WSG	AO Firma Avgust, Russia
Lontrel grand, WSG	Dow AgroSciences Vertriebsgesellschaft m.b.H, Austria
Demetra, EC	AO Firma Avgust,, Russia
Starane Premium 330, EC	Dow AgroSciences Vertriebsgesellschaft m.b.H, Austria
Esteron 600, EC	Dow AgroSciences Vertriebsgesellschaft m.b.H, Austria
Drotik, CSC	AO Shchelkovo Agrokhim, Russia
Estet, EC	«Nufarm GmbH & Co KG», Austria
Laren Pro, WSG	OOO Dyupon Nauka i Tekhnologii, Russia
Tribun, DFC	OOO Agro Ekspert Grup, Russia
Prima, EC	Dow AgroSciences Vertriebsgesellschaft m.b.H, Austria
Bomba, WSG	AO Firma Avgust, Russia
Unico, CSC	AO Shchelkovo Agrokhim, Russia
Modern, EC	OOO GK ZemlyaFF, Russia
Classic Forte, WSG	OOO Dyupon Nauka i Tekhnologii, Russia
Fabian, WSG	AO Firma Avgust,, Russia
Express, WSG	OOO EfEmSi, Russia
Sanflo, WSG	AO Shchelkovo Agrokhim, Russia
Prometei, WSG	OOO Yarilo, Russia
Titus, DFC	OOO Dyupon Nauka i Tekhnologii, Russia
Cassius, WS	AO Shchelkovo Agrokhim, Russia
Escudo, WDG	AO Firma Avgust, Russia
Gensek, WSG	OOO Agro-Innovatsii, Russia; OOO Agruskhim, Russia
Gorgon, WSC	AO Firma Avgust, Russia
Oktimet, EC	OOO Alsiko Agroprom, Russia; OOO Agroimpeks, Russia
Lancelot 450, WDG	Dow AgroSciences Vertriebsgesellschaft m.b.H, Austria
Agron, WS	OOO Agro Ekspert Grup, Russia
Agron Grand, WDG	OOO Agro Ekspert Grup, Russia
Primadonna, EC	AO Shchelkovo Agrokhim, Russia
Balerina, EC	AO Firma Avgust, Russia
MaysTer, WDG	Bayer CropScience AG, Germany
MaysTer Power, OD	Bayer CropScience AG, Germany
Pulsar, WS	BASF Agrochemical Products B.V., the Netherlands
Pivot, WC	BASF Agrochemical Products B.V., the Netherlands
Bazagran, WS	BASF SE, Germany
Corsar, WSC	AO Firma Avgust, Russia
Benito, DF	AO Shchelkovo Agrokhim, Russia
Corum, WSC	BASF Agrochemical Products B.V., the Netherlands
Euro-Lightning, WSC	BASF Agrochemical Products B.V., the Netherlands
Pulsar, WS	BASF Agrochemical Products B.V., the Netherlands
Tapir Hybrid, OC	OOO Agro Ekspert Grup, Russia
Titus, CTC	OOO Dyupon Nauka i Tekhnologii, Russia
Cassius, WSP	AO Shchelkovo Agrokhim, Russia
Nissin, SC	ISK Biosciences Europe N.V., Belgium
Ikanos, OD	Nufarm GmbH & Co KG, Austria
Innovate, SC	Cheminova A/C, Denmark
DUBLON, SC	AO Firma Avgust, Russia
Cordus, WDG	OOO Dyupon Nauka i Tekhnologii, Russia
Elumis, OD	OOO Singenta, Russia
Fuzilad Super, EC	OOO Singenta, Russia
Bagira, EC	Arysta LifeScience Great Britain Ltd., UK
Pantera, EC	Arysta LifeScience Great Britain Ltd., UK
Healer, OEC	AO Shchelkovo Agrokhim, Russia
Select, EC	Arysta LifeScience S.A.S., France
Centurion, EC	Arysta LifeScience S.A.S., France
Puma Super 7.5, OWE	Bayer CropScience AG, Germany
Ocelot, EC	OOO Agro Ekspert Grup, Russia
Topic, EC	OOO Singenta, Russia
Axial 50, EC	OOO Singenta, Russia
Everest, WDG	Arysta LifeScience S.A.S., France
Alister Grand, OD	Bayer CropScience AG, Germany
Ocelot Cross, EC	OOO Agro Ekspert Grup, Russia
Zencor Ultra, SC	«Bayer CropScience AG», Germany
Lazurit, SP	AO Firma Avgust, Russia
Soil, WSG	OOO Agro Ekspert Grup, Russia
Tornado, WS	AO Firma Avgust, Russia
Total, WS	OOO Agro Ekspert Grup, Russia
Ankor-85, WSG	OOO Gerbivid Pervii, Russia
Zinger, SP	AO Shchelkovo Agrokhim, Russia
Shkval, WC	AO Shchelkovo Agrokhim, Russia
Arbonal, WC	OOO Novokemi, Russia

Continued list

AtronPro, WSG	OOO Agruskhim, Russia
Gorgon, WSC	AO Firma Avgust, Russia
Grange, WSG	ZAO Unaited Agro, Russia; ZAO NPF Golitsyno Agro, Russia
Gensec, WSG	OOO Agro-Innovatsii, Russia; OOO Agruskhim, Russia
Banvel, WS	OOO Singenta Russia
Dianat, WS	BASF Corporation, USA

Therefore, biological and biorational herbicides in the near future may occupy niches in the assortment of weed protection products in orchards and vineyards, in fields for sowing spring crops (when carrying out protective measures in the autumn) and in fallow fields. The development of bioherbicides against perennial root-sprouting weeds and Russian knapweed is promising for combating these species during the growing season of soybeans, sunflowers, and potatoes. For the last two crops during the growing season, the use of biological products against common ragweed looks promising. Such preparations are also of interest as additional methods of operative weed control along with chemical herbicides. The status of quarantine objects for wormwood-leaved ragweed and Russian knapweed should contribute to the interest of buyers in new environmentally friendly means of combating them, even in the presence of a large number of chemicals. In addition, existing chemicals against the Russian knapweed have side effects, which limit their use in industrial conditions. It will be quite challenging to occupy the niche associated with the destruction of cereal weeds (such as couch grass or wild oats) by bioherbicides in the conditions of the existing range of chemical preparations. A possible direction of their use may be the suppression of resistant populations of these weeds due to the large-scale use of chemical herbicides.

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