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REVIEW

Regulatory differences in crop protection systems for soybean production: implications of the EU–Mercosur trade agreement

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Abstract

The political conclusion of the EU–Mercosur Partnership Agreement in December 2024 marks a significant shift in global agri-food trade and raises fundamental questions on regulatory coherence in plant protection. This study provides a comprehensive comparative assessment of crop protection systems in soybean (*Glycine max* L.) production between the European Union (represented by Poland) and Mercosur countries. Soybean was selected due to its strategic importance in global feed supply chains, the EU's structural import dependence, and the crop's high reliance on chemical and biological plant protection products (PPPs). The analysis reveals pronounced asymmetries in the availability of authorized active substances. Mercosur producers have access to 96 herbicide active substances compared to 16 in Poland (ratio 6 : 1); 96 chemical fungicide active substances compared to 5 (19 : 1); and 94 chemical insecticide active substances compared to only 2 (47 : 1). The disparity is particularly striking for biological fungicides, where 104 microbial strains are registered in Mercosur versus 2 in Poland (52 : 1). Even in biological insecticides, the ratio remains 3 : 1 (9 vs. 3). Approximately 100 active substances used in Mercosur soybean production are not approved in the EU. Pesticide application intensity in Brazil (12.63 kg a.s./ha) is 4.7 times higher than the EU average and over seven times higher than in Poland. In parallel, Maximum Residue Limits (MRLs) for selected substances differ substantially, in extreme cases by up to 200-fold. These quantitative asymmetries translate into divergent pest management capacity, resistance management flexibility, and production resilience. While the EU regulatory framework reflects a precautionary approach with progressive restriction of active substances, Mercosur systems operate with substantially broader chemical and biological portfolios enabling diversified and rotation-based control strategies. The findings demonstrate that regulatory differences – ranging from 6 : 1 to 52 : 1 depending on product category – constitute a structural factor shaping competitiveness, resistance risk, and food safety governance under the evolving EU–Mercosur trade framework.

Keywords: agricultural policy, international trade, MRLs, pesticide regulation, plant protection products

Introduction

The European Union (EU) and the Mercosur bloc reached a political agreement in December 2024 in an Association Agreement that had been under negotiation for over 25 years (European Commission 2024). This historic agreement establishes one of the world's largest free trade areas, covering a combined population of approximately 780 million people and representing nearly 20% of global gross domestic product (GDP). For the agricultural sector, this agreement carries profound implications, as it will progressively reduce tariffs and trade barriers on agricultural commodities, fundamentally altering competitive dynamics on global food markets.

The agricultural dimensions of this agreement are particularly significant given the contrasting production systems and regulatory philosophies of the two trading blocs (de Oliveira *et al*. 2024). The European Union has pursued an increasingly precautionary approach to pesticide regulation under the Common Agricultural Policy and more recently the Green Deal and Farm to Fork Strategy, resulting in the withdrawal of numerous active substances from the market (Korbas *et al*. 2017; Strażyński *et al*. 2025). Mercosur countries, conversely, have maintained broader pesticide portfolios to address the intensive pest and disease pressures characteristic of tropical and subtropical agricultural systems. Brazil, a major global agricultural player, ranks among the top five agro-food producers and exporters, making it one of the largest consumers of pesticides worldwide. Notably, approximately 30% of the pesticides used in Brazil are banned in the European Union. Paradoxically, some of these banned agrochemicals re-enter northern markets through imported agro-food products (Bombardi 2019; Perobelli 2025).

This study provides a comprehensive comparative analysis of crop protection systems between the EU (represented by Poland) and Mercosur countries, using soybean (*Glycine max* L.) as the primary model crop. Soybean was selected for several compelling reasons: it represents the dominant crop in Mercosur agricultural production, accounting for approximately 40% of Brazil's total crop output; the EU imports over 50% of its soybean and soybean meal requirements from Mercosur, creating a fundamental structural dependency; the contrasting regulatory approaches are most starkly evident in this crop; and the intensive pest pressure in tropical soybean production has driven registration of an exceptionally broad portfolio of plant protection products, enabling meaningful comparison (Bułkowska and Ambroziak 2025; Gohin and Matthews 2025).

Key drivers of regulatory divergence include differences in risk assessment frameworks, with the EU applying a hazard-based approach leading to the withdrawal of substances due to carcinogenicity, endocrine disruption, persistence, and ecotoxicological risks.

Materials and Methods

Scope and study design

The analysis was based on a comparative assessment of plant protection products authorized for soybean (*G. max*) cultivation in Poland and in Mercosur countries (Brazil, Argentina, Bolivia, Paraguay, and Uruguay). Poland was selected as a representative case for the European Union due to the harmonized nature of EU pesticide regulation and the availability of detailed national registration data.

Data sources

Information on authorized plant protection products and active substances in Poland was obtained from the national register maintained by a competent authority, supplemented by unpublished expert analyses conducted at the Institute of Plant Protection – National Research Institute. Data for Mercosur countries were compiled from official national registers, regulatory agency publications, and pesticide sales and use statistics, particularly reports issued by IBAMA (2025) and FAOSTAT (2024) and internet database HOMOLOGA (2025). Active substances were classified into herbicides, fungicides, and insecticides, with further distinction between chemical and biological products. Microbial biological agents were treated at strain level where national regulations recognize individual strains as separate active substances.

Comparative framework

Comparisons focused on: (i) the number of authorized active substances by functional group; (ii) diversity of modes of action relevant to resistance management; and (iii) regulatory status of substances under EU legislation. Maximum Residue Limits (MRLs) were compared using EU Regulation (EC) No 396/2005 and corresponding Brazilian standards.

Results

The Mercosur Bloc: agricultural characteristics

Overview and agricultural potential

Mercosur (Mercado Común del Sur) comprises Brazil, Argentina, Paraguay, Uruguay, and Bolivia, representing one of the world's most important agricultural production regions. The bloc encompasses approximately 389 million hectares of agricultural land – 2.4 times the agricultural area of the entire European Union. This vast territory, combined with favorable climatic conditions and abundant natural resources, positions Mercosur as a global agricultural powerhouse with production potential that significantly exceeds current output levels.

The agricultural structure of Mercosur differs fundamentally from the European model. While the EU maintains approximately 10.3 million farms with an average size of 17.4 hectares (the average farm size in Poland is approximately 11 ha), Mercosur agriculture is characterized by large-scale commercial operations, particularly in the dominant soybean and cattle sectors. Brazilian farms in the Cerrado and Matopiba regions frequently exceed 1,000 hectares, enabling economies of scale in mechanization and input application that are rarely achievable in European contexts.

Crop production and GMO technology adoption

Mercosur countries have embraced genetically modified crop technology to an extent unmatched elsewhere in the world. The bloc accounts for approximately 46.5% of global Genetically Modified Organisms (GMOs) crop cultivation area, with Brazil alone representing 26.4% of the world total. GMO soybean varieties, primarily those with herbicide tolerance (HT) and insect resistance (IR) traits, dominate production in all major Mercosur producing countries. In Brazil, over 97% of the soybean area is planted with GM varieties, compared to effectively zero in the European Union where GMO crop cultivation remains restricted to a single approved maize variety grown on limited area in Spain and Portugal.

Soybean production represents the cornerstone of Mercosur agriculture. Brazil is the world's largest soybean producer with an annual output exceeding 150 million tonnes, followed by Argentina with approximately 50 million tonnes. Paraguay ranks as the world's fourth-largest soybean exporter despite its relatively small territory. Collectively, Mercosur accounts for over 50% of global soybean exports, making the bloc the dominant supplier to import-dependent regions including the European Union, China, and Southeast Asia.

Plant protection products market: Mercosur vs. European Union

Market size and sales volume

Brazil has emerged as the world's largest consumer of plant protection products, with annual sales reaching approximately 15–16 billion USD. This represents roughly 20% of the global pesticide market concentrated in a single country. The scale of Brazilian pesticide consumption reflects the combination of vast cultivated area, intensive production systems, year-round pest pressure in tropical conditions, and the dominance of crops requiring substantial chemical inputs.

According to IBAMA (Brazilian Institute of Environment and Renewable Natural Resources) data for 2022, total pesticide sales in Brazil reached 809,722 tonnes of active substance. This extraordinary volume is distributed across herbicides (approximately 60% of total use), insecticides (15%), and fungicides (12%), with the remainder comprising other product categories. The 10 most-sold active substances in Brazil account for over 60% of total consumption, indicating significant concentration around key molecules.

Application intensity comparison

Pesticide application intensity – measured as kilograms of active substance applied per hectare of agricultural land – reveals fundamental differences between production systems (Tab. 1). Brazil's application intensity of 12.63 kg active substance per hectare is 4.68 times the EU average and 7.3 times higher than Poland's intensity. This reflects both the broader portfolio of available products and the more intensive pest and disease pressure in tropical production systems. Even Argentina and Uruguay, with more temperate climates, maintain intensities 2.3–2.7 times the EU average.

Table 1. Pesticide application intensity comparison: Mercosur countries vs. European Union (FAOSTAT 2024)

Country/Region	Application intensity [kg a.s. · ha^{-1}]	Ratio to EU average
Brazil	12.63	4.68×
Argentina	6.33	2.34×
Uruguay	7.35	2.72×
Paraguay	3.98	1.47×
Mercosur average	9.41	3.49×
EU average	2.70	1.00×
Poland	1.73	0.64×

Most-used active substances in Brazil

Analysis of IBAMA sales data reveals the dominant role of a relatively small number of active substances in Brazilian agriculture, with significant implications

Table 2. Ten most-sold active substances in Brazil (2022) and their EU regulatory status (IBAMA 2025)

No	Active substance	Sales 2022 [tonnes]	EU regulatory status
1	Glyphosate	382.784	approved (under review)
2	2,4-D	101.887	approved
3	Mancozeb	50.532	banned (2021)
4	Atrazine	77.029	banned (2007)
5	Paraquat	24.894	banned (2007)
6	Acephate	28.746	banned (2003)
7	Imidacloprid	17.295	restricted (2018)
8	Chlorothalonil	15.127	banned (2020)
9	Mineral oil	43.857	approved
10	Sulfur	38.940	approved

for EU import controls (Tab. 2). Critically, eight of the 10 most-used active substances in Brazilian agriculture are either banned or heavily restricted in the European Union. Glyphosate, representing 47% of total sales by volume, remains under contentious regulatory review in the EU. Atrazine (banned 2004), mancozeb (banned 2021), paraquat (banned 2007), acephate (banned 2003), and chlorothalonil (banned 2019) continue to be applied at scale in Brazilian production systems, with residues potentially present on exported commodities.

Active substances in soybean protection: detailed analysis

Herbicides

Weed control is a critical determinant of soybean yield stability. In Poland, soybean protection relies on 16 herbicide active substances, primarily ACCase inhibitors and a limited number of pre-emergence herbicides, supplemented by glyphosate. In contrast, Mercosur countries have access to 96 herbicide active substances representing a wide range of chemical classes and modes of action. The restricted herbicide portfolio in Poland limits opportunities for rotation of modes of action and increases the risk of resistance development, a phenomenon widely documented for ALS- and ACCase-inhibiting herbicides in European arable systems (Heap 2025; Stankiewicz-Kosyl *et al.* 2020, 2021, 2023). In Mercosur systems, broader portfolios allow for diversified programs combining pre- and post-emergence herbicides, which is particularly important in intensive soybean monocultures.

Weed management represents the most critical aspect of soybean crop protection, as early-season competition can reduce yields by 20–50%. The analysis reveals that Poland has 117 registered commercial herbicide products based on 16 active substances, while Mercosur countries collectively access 96 different active substances. Only seven substances are common to both systems: bentazone, clomazone, clethodim, glyphosate, imazamox, pendimethalin, and propaquizafop.

Typical weed flora also differs between regions and reflects both climatic conditions and management systems. In Poland and under other EU conditions, dominant weed species include *Chenopodium album* and *Amaranthus spp.* In contrast, soybean production systems in Mercosur are increasingly challenged by herbicide-resistant populations, particularly glyphosate-resistant *Amaranthus spp.* and *Conyza spp.* (Procópio *et al.* 2024), which require more diverse and intensive herbicide programs. Despite the limited herbicide portfolio, acceptable weed control may still be achieved under moderate pressure through integrated approaches combining mechanical control and crop rotation.

Herbicide active substances registered in Poland

The Polish herbicide portfolio is dominated byACCase inhibitors (graminicides) (Tab. 3). The availability of broadleaf weed herbicides is notably limited, with bentazone providing the primary option. This narrow spectrum constrains integrated weed management strategies and increases resistance development risk (HRAC 2026).

Table 3. Herbicide active substances registered for soybean protection in Poland (2024) (Source: author's own elaboration based on HOMOLOGA 2025)

Active substance	Chemical group (Mode of Action/HRAC)	Products
Bentazon	Benzothiadiazinones (PSII inhibitors/6)	8
Quizalofop-P-ethyl	FOPs (ACCase inhibitors/1)	6
Cycloxydim	DIMs (ACCase inhibitors/1)	4
Dimethenamid-P	Chloroacetamides (VLCFA inhibitors/15)	3
Fluazifop-P-butyl	FOPs (ACCase inhibitors/1)	5
Clomazone	Isoxazolidinones (DXPS inhibitors/13)	4
Imazamox	Imidazolinones (ALS inhibitors/2)	3
Clethodim	DIMs (ACCase inhibitors/1)	7
Metobromuron	Ureas (PSII inhibitors/5)	2
Pendimethalin	Dinitroanilines (microtubule inhibitors/3)	6
Pethoxamid	Chloroacetamides (VLCFA inhibitors/15)	2
Propaquizafop	FOPs (ACCase inhibitors/1)	4
Prosulfocarb	Thiocarbamates (VLCFA inhibitors/15)	3
Pyraflufen-ethyl	Phenylpyrazoles (PPO inhibitors/14)	2
Thifensulfuron-methyl	Sulfonylureas (ALS inhibitors/2)	3

Comparative analysis: Poland vs. Mercosur herbicides

Mercosur countries have access to numerous substances banned or never registered in the EU, including atrazine, paraquat, and various 2,4-D formulations for herbicide-tolerant varieties. PPO inhibitors (fomesafen, flumioxazin, sulfentrazone, lactofen, saflufenacil) provide powerful broadleaf control options unavailable in Poland (Tab. 4).

Fungicides

Chemical fungicide protection of soybean in Poland is based on five active substances representing four modes

Table 4. Comparative availability of herbicide active substances for soybean: Poland vs. Mercosur (Source: author's own elaboration based on HOMOLOGA 2025)

Active Substance	Chemical group (Mode of Action/HRAC)	BR	AR	BO	UY	PY	PL
2,4-D	Phenoxycarboxylates (auxin mimics/4)	✓	–	–	–	✓	–
Acetochlor	Chloroacetamides (VLCFA inhibitors/15)	✓	✓	–	✓	–	–
Atrazine	Triazines (PSII inhibitors/6)	✓	✓	–	–	–	–
Bentazon	Benzothiadiazinones (PSII inhibitors/6)	✓	✓	✓	–	–	✓
Chlorimuron-ethyl	Sulfonylureas (ALS inhibitors/2)	✓	✓	–	–	–	–
Clethodim	DIMs (ACCase inhibitors/1)	✓	✓	✓	✓	✓	✓
Clomazone	Isoxazolidinones (DXPS inhibitors/13)	✓	✓	–	–	–	✓
Cycloxydim	DIMs (ACCase inhibitors/1)	–	–	–	–	–	✓
Dicamba	Benzoates (auxin mimics/4)	✓	–	–	–	–	–
Diclosulam	Triazolopyrimidines (ALS inhibitors/2)	✓	✓	✓	✓	–	–
Diuron	Ureas (PSII inhibitors/5)	✓	–	–	–	–	–
Fluazifop-P-butyl	FOPs (ACCase inhibitors/1)	✓	–	–	✓	–	✓
Flumioxazin	N-phenylimides (PPO inhibitors/14)	✓	✓	✓	✓	–	–
Fomesafen	Diphenyl ethers (PPO inhibitors/14)	✓	✓	✓	✓	✓	–
Glufosinate-ammonium	Phosphinic acids (GS inhibitors/10)	✓	✓	–	✓	–	–
Glyphosate	Organophosphonate and glycine derivative (EPSPS inhibitors/9)	✓	✓	–	✓	✓	–
Haloxyfop-P-methyl	FOPs (ACCase inhibitors/1)	✓	–	✓	✓	–	–
Imazamox	Imidazolinones (ALS inhibitors/2)	✓	✓	–	–	–	✓
Imazethapyr	Imidazolinones (ALS inhibitors/2)	✓	✓	✓	✓	✓	–
Lactofen	Diphenyl ethers (PPO inhibitors/14)	✓	✓	–	–	–	–
Metobromuron	Ureas (PSII inhibitors/5)	–	–	–	–	–	✓
Metribuzin	Triazinones (PSII inhibitors/5)	✓	✓	✓	✓	–	✓
Paraquat	Pyridiniums (PS I electron diversion/22)	–	✓	–	✓	✓	–
Pendimethalin	Dinitroanilines (microtubule inhibitors/3)	–	✓	✓	–	–	✓
Pethoxamid	Chloroacetamides (VLCFA inhibitors/15)	–	–	–	–	–	✓
Propaquizafop	FOPs (ACCase inhibitors/1)	✓	✓	–	✓	–	✓
Prosulfocarb	Thiocarbamates (VLCFA inhibitors/15)	–	–	–	–	–	✓
Pyraflufen-ethyl	Phenylpyrazoles (PPO inhibitors/14)	✓	–	–	–	–	✓
Quizalofop-P-ethyl	FOPs (ACCase inhibitors/1)	✓	✓	✓	–	–	✓
S-metolachlor	Chloroacetamides (VLCFA inhibitors/15)	✓	✓	✓	✓	–	–
Saflufenacil	N-phenylimides (PPO inhibitors/14)	✓	✓	–	–	–	–
Sulfentrazone	N-phenyltriazolinones (PPO inhibitors/14)	✓	✓	✓	✓	–	–
Thifensulfuron-methyl	Sulfonylureas (ALS inhibitors/2)	–	–	–	–	–	✓
Trifluralin	Dinitroanilines (microtubule inhibitors/3)	✓	✓	–	✓	–	–

BR – Brazil, AR – Argentina, BO – Bolivia, UY – Uruguay, PY – Paraguay, PL – Poland

of action, with strong reliance on triazoles and strobilurins. Such a narrow spectrum constrains resistance management and limits response options under high disease pressure, particularly in relation to quinone outside inhibitors (QoI) and demethylation inhibitors (DMI) fungicide resistance development (Lucas *et al*. 2014; FRAC 2025). Mercosur countries have access to 96 chemical fungicide active substances, including multi-site inhibitors, numerous triazoles, succinate dehydrogenase inhibitor fungicides (SDHIs), and combination products (Bombardi 2019; IBAMA 2025). This diversity is essential for managing Asian soybean rust and illustrates how regulatory frameworks influence disease management strategies.

Fungal disease pressure and composition differ markedly between regions. Under Poland and broader

EU conditions, the most relevant soybean diseases include *Sclerotinia sclerotiorum* and *Peronospora manshurica*, which are typically associated with temperate climates and moderate disease pressure. In contrast, soybean production in Mercosur is strongly affected by highly aggressive pathogens such as Asian soybean rust (*Phakopsora pachyrhizi*) and *Cercospora spp.*, which require intensive and often multi-site fungicide programs for effective control (Yorinori *et al.* 2005; Hartman *et al.* 2015).

Fungal disease management in soybean presents the most dramatic asymmetry between regions. Poland has 25 chemical fungicide products based on only five active substances, plus four biological products based on two microbial strains. Mercosur countries collectively access 96 chemical fungicide active substances and 104 biological fungicide strains – ratios of 19 : 1 and 52 : 1, respectively.

Chemical fungicide active substances registered in Poland

Polish fungicide protection relies on QoI strobilurins (azoxystrobin) and DMI triazoles (prothioconazole, difenoconazole) (Tab. 5). These 31 commercial products represent only two primary modes of action, creating significant resistance management concerns.

Table 5. Chemical fungicide active substances registered for soybean protection in Poland (2024) (Source: author's own elaboration based on HOMOLOGA 2025)

Active substance	Chemical group (Mode of Action/FRAC)	Products
Azoxystrobin	Strobilurins (QoI/11)	12
Difenoconazole	Triazoles (DMI/3)	5
Fludioxonil	Phenylpyrroles (M-O-G-D/12)	2
Fluopyram	Benzamides (SDHI/7)	1
Prothioconazole	Triazoles (DMI/3)	11

Comparative analysis: Poland vs. Mercosur chemical fungicides

Mercosur farmers have access to numerous fungicide classes unavailable in Poland, including dithiocarbamates (mancozeb, thiram – withdrawn from EU), benzimidazoles (carbendazim – banned), and multiple SDHI compounds (Tab. 6). Brazil's comprehensive portfolio addresses Asian soybean rust (*Phakopsora pachyrhizi*), requiring preventive multi-site programs impossible with Poland's limited substances.

Biological fungicides

The disparity in biological fungicide availability is particularly pronounced. Poland has only two authorized

Table 6. Comparative availability of chemical fungicide active substances for soybean: Poland vs. Mercosur (Source: author's own elaboration based on HOMOLOGA 2025)

Active substance	Chemical group (Mode of Action/FRAC)	BR	AR	BO	UY	PY	PL
Azoxystrobin	Strobilurins (QoI/11)	✓	✓	✓	✓	✓	✓
Benthiavalicarb	Carbamates (CAA/40)	✓	–	–	–	–	–
Boscalid	Pyrazole carboxamides (SDHI/7)	✓	✓	–	–	–	–
Carbendazim	Benzimidazoles (B-MT-G-ATP/1)	✓	✓	✓	✓	–	–
Chlorothalonil	Chloronitriles (S-E-G-D/M05)	✓	✓	–	✓	–	–
Cyproconazole	Triazoles (DMI/3)	✓	✓	✓	✓	–	–
Difenoconazole	Triazoles (DMI/3)	✓	✓	✓	✓	✓	✓
Dimoxystrobin	Strobilurins (QoI/11)	✓	–	–	–	–	–
Epoxiconazole	Triazoles (DMI/3)	✓	✓	–	✓	–	–
Fludioxonil	Phenylpyrroles (M-O-G-D/12)	✓	✓	✓	✓	–	✓
Fluopyram	Benzamides (SDHI/7)	✓	–	–	–	–	✓
Flutriafol	Triazoles (DMI/3)	✓	✓	–	–	–	–
Fluxapyroxad	Pyrazole carboxamides (SDHI/7)	✓	✓	–	✓	–	–
Isopyrazam	Pyrazole carboxamides (SDHI/7)	✓	–	–	–	–	–
Kresoxim-methyl	Strobilurins (QoI/11)	✓	✓	–	–	–	–
Mancozeb	Dithiocarbamates (S-M-R-D/M03)	✓	✓	✓	✓	✓	–
Metconazole	Triazoles (DMI/3)	✓	✓	–	–	–	–
Myclobutanil	Triazoles (DMI/3)	✓	✓	–	–	–	–
Picoxystrobin	Strobilurins (QoI/11)	✓	✓	✓	✓	–	–
Propiconazole	Triazoles (DMI/3)	✓	✓	✓	✓	–	–

Table 6. Comparative availability of chemical fungicide active substances for soybean: Poland vs. Mercosur (Source: author's own elaboration based on HOMOLOGA 2025) – continuation

Active substance	Chemical group (Mode of Action/FRAC)	BR	AR	BO	UY	PY	PL
Prothioconazole	Triazoles (DMI/3)	✓	✓	✓	✓	✓	✓
Pydiflumetofen	N-methoxyphenyl pyrazolecarboxamides (SDHI/7)	✓	✓	–	–	–	–
Pyraclostrobin	Strobilurins (QoI/11)	✓	✓	✓	✓	✓	–
Tebuconazole	Triazoles (DMI/3)	✓	✓	✓	✓	✓	–
Thiophanate-methyl	Thiophanates (B-M-M-D/1)	✓	✓	✓	✓	–	–
Thiram	Dithiocarbamates (S-E-R-D/M3)	✓	✓	✓	✓	–	–
Trifloxystrobin	Strobilurins (QoI/11)	✓	✓	✓	✓	–	–

BR – Brazil, AR – Argentina, BO – Bolivia, UY – Uruguay, PY – Paraguay, PL – Poland

microbial strains for soybean, whereas Mercosur countries register 104 strains. This diversity enables strain-specific selection and integration of biological products into disease management programs, whereas limited availability in the EU constrains practical implementation of biological control.

The disparity in biological control agents represents the most striking finding. Poland's biological options are limited to *Bacillus amyloliquefaciens* (strains QST713, FZB24) and *Trichoderma asperellum* T34. Brazil registers over 60 *Bacillus* strains and 30+ *Trichoderma* strains, each as separate active substances, providing extensive strain-specific selection for local conditions (Tab. 7).

Table 7. Biological fungicide strains registered for soybean protection: Mercosur vs. Poland (Source: author's own elaboration based on HOMOLOGA 2025)

Microbial species/group	No. of strains	Countries
Bacillus amyloliquefaciens (total)	18	BR, BO, UY, PL
Bacillus subtilis (total)	16	BR, BO
Bacillus velezensis (total)	19	BR, UY
Bacillus pumilus (total)	5	BR
Bacillus licheniformis (total)	4	BR
Trichoderma harzianum (total)	14	BR, BO
Trichoderma asperellum (total)	9	BR, BO, UY, PL
Trichoderma atroviride	2	BR, AR
Trichoderma gamsii	2	BO, UY
Trichoderma koningii	1	BO
Other *Trichoderma* spp.	5	BR, BO, UY
Saccharomyces cerevisiae	1	BR
Plant extracts	4	BR, BO
TOTAL STRAINS	104 (Mercosur) vs. 2 (Poland)	

BR – Brazil, AR – Argentina, BO – Bolivia, UY – Uruguay, PY – Paraguay, PL – Poland

Insecticides

Only two chemical insecticide active substances are authorized for soybean in Poland, providing a very narrow range of modes of action and limiting implementation of insecticide resistance management strategies (Sparks and Nauen 2015; IRAC 2026). Mercosur countries, by contrast, have access to 94 chemical insecticide active substances, supporting diversified and resistance-aware insect pest management strategies.

The spectrum and intensity of insect pest pressure differ substantially between regions. Under Poland and broader EU conditions, the most relevant soybean pests include aphids (*Aphis spp.*), cutworms, and *Sitona spp.*, which are typically associated with moderate and seasonal pest pressure. In contrast, soybean production in Mercosur is affected by more aggressive and economically significant pests such as *Helicoverpa armigera* and stink bugs (*Euschistus spp.*), often requiring intensive and repeated insecticide applications (Bueno *et al*. 2013; Hartman *et al*. 2015; Lamichhane 2017; Oliveira *et al*. 2017).

Insect pest management reveals the most extreme asymmetry. Poland has only 10 commercial insecticide products based on two active substances (cypermethrin, acetamiprid) for soybean. Mercosur countries have access to 94 chemical insecticide active substances – a ratio of 47 : 1 (Tab. 8). Additionally, Poland has four biological products based on three substances, while Mercosur has nine biological insecticide substances (Tab. 9). The Mercosur insecticide portfolio includes chemical classes unavailable in Poland: diamides (chlorantraniliprole, flubendiamide, cyantraniliprole); multiple pyrethroids providing formulation flexibility; spinosyns (spinetoram, spinosad) with reduced environmental impact; organophosphates and carbamates largely withdrawn from EU; and benzoylureas and other insect growth regulators (IGRs) for caterpillar management. Mercosur farmers can implement sophisticated resistance management

Table 8. Comparative availability of insecticide active substances for soybean: Poland vs. Mercosur (Source: author's own elaboration based on HOMOLOGA 2025)

Active substance	Chemical group (Mode of Action/IRAC)	BR	AR	BO	UY	PY	PL
Abamectin	Avermectins (GluCl allosteric modulators/6)	✓	✓	✓	✓	✓	–
Acephate	Organophosphates (AChE inhibitors/1B)	✓	–	–	✓	✓	–
Acetamiprid	Neonicotinoids (nAChR competitive modulators/4A)	✓	✓	✓	✓	–	✓
Alpha-cypermethrin	Pyrethroids (Sodium channel modulators/3A)	✓	✓	✓	–	✓	–
Beta-cyfluthrin	Pyrethroids (Sodium channel modulators/3A)	✓	✓	✓	–	–	–
Bifenthrin	Pyrethroids (Sodium channel modulators/3A)	✓	✓	✓	✓	✓	–
Chlorantraniliprole	Diamides (ryanodine receptor modulators/28)	✓	✓	✓	✓	–	–
Chlorfenapyr	Pyrroles (proton gradient disruptors/13)	✓	✓	✓	–	–	–
Chlorpyrifos	Organophosphates (AChE inhibitors/1B)	✓	–	✓	–	–	–
Cyantraniliprole	Diamides (ryanodine receptor modulators/28)	✓	–	✓	✓	–	–
Cypermethrin	Pyrethroids (Sodium channel modulators/3A)	✓	–	✓	✓	–	✓
Deltamethrin	Pyrethroids (Sodium channel modulators/3A)	✓	–	–	✓	–	–
Diflubenzuron	Benzoylureas (inhibitors of chitin biosynthesis affecting CHS1/15)	✓	✓	✓	–	✓	–
Dinotefuran	Neonicotinoids (nAChR competitive modulators/4A)	✓	✓	✓	✓	–	–
Emamectin benzoate	Avermectins (GluCl allosteric modulators/6)	✓	✓	✓	✓	✓	–
Esfenvalerate	Pyrethroids (Sodium channel modulators/3A)	✓	✓	✓	–	–	–
Fipronil	Phenylpyrazoles (GABA-gated chloride channel blockers/2B)	✓	✓	✓	–	✓	–
Flubendiamide	Diamides (ryanodine receptor modulators/28)	✓	✓	✓	–	–	–
Imidacloprid	Neonicotinoids (nAChR competitive modulators/4A)	✓	✓	✓	✓	✓	–
Lambda-cyhalothrin	Pyrethroids (Sodium channel modulators/3A)	✓	✓	✓	✓	✓	–
Lufenuron	Benzoylureas (inhibitors of chitin biosynthesis affecting CHS1/15)	✓	✓	–	✓	✓	–
Methomyl	Carbamates (AChE inhibitors/1A)	✓	✓	✓	–	–	–
Methoxyfenozide	Diacylhydrazines (ecdysone receptor agonists/18)	✓	✓	✓	✓	–	–
Novaluron	Benzoylureas (inhibitors of chitin biosynthesis affecting CHS1/15)	✓	✓	✓	–	–	–
Profenofos	Organophosphates (AChE inhibitors/1B)	✓	✓	–	✓	✓	–
Spinetoram	Spinosyns (nAChR allosteric modulators/5)	✓	✓	–	✓	–	–
Spinosad	Spinosyns (nAChR allosteric modulators/5)	✓	✓	✓	✓	–	–
Spiromesifen	Tetronic acid derivatives (acetyl CoA carboxylase inhibitors/23)	✓	✓	✓	✓	–	–
Sulfoxaflor	Sulfoximines (nAChR competitive modulators/4C)	✓	✓	–	–	–	–
Teflubenzuron	Benzoylureas (inhibitors of chitin biosynthesis affecting CHS1/15)	✓	✓	✓	✓	–	–
Thiamethoxam	Neonicotinoids (nicotinic acetylcholine receptor competitive modulators/4A)	✓	✓	✓	✓	✓	–

BR – Brazil, AR – Argentina, BO – Bolivia, UY – Uruguay, PY – Paraguay, PL – Poland

with multiple modes of action, while Polish farmers are limited to essentially two mechanisms.

Comparative analysis: Poland vs. Mercosur insecticides

The comparative analysis of insecticide availability demonstrates a pronounced asymmetry between Poland and Mercosur countries. Polish soybean production relies on an extremely limited insecticide toolbox, encompassing only two chemical active substances (Tab. 8) and a narrow range of biological agents (Tab. 9), which severely restricts the diversity of modes of action available for pest control. In contrast, Mercosur production systems benefit from broad and functionally diverse chemical and biological insecticide portfolios, enabling rotation of modes of action, stage-specific pest targeting, and integration of chemical

Table 9. Biological insecticide substances for soybean: Poland vs. Mercosur (Source: author's own elaboration based on HOMOLOGA 2025)

Active substance	Type	Poland	Mercosur
Bacillus thuringiensis	bacterium	✓	✓
Beauveria bassiana	entomopathogenic fungus	✓	✓
Sheep fat (repellent)	natural repellent	✓	–
Bacillus firmus	bacterium (nematicide)	–	✓
Paecilomyces lilacinus	entomopathogenic fungus	–	✓
Pasteuria nishizawae	bacterium (nematicide)	–	✓
Argemone mexicana extract	plant extract	–	✓

and biological approaches. This disparity substantially constrains the implementation of insecticide resistance management and integrated pest management strategies in Poland, while providing greater flexibility and resilience in Mercosur soybean protection systems.

Table 10. Comparison of Maximum Residue Limits (MRLs) in the EU and Brazil for selected active substances used in soybean

Active substance	EU MRL $[\mathrm{mg \cdot kg^{-1}}]$	Brazil MRL $[\mathrm{mg \cdot kg^{-1}}]$	Ratio
Glyphosate	20	10	EU 2 × higher
2,4-D	0.05	0.1	BR 2 × higher
Chlorothalonil*	0.01	0.5	BR 50 × higher
Mancozeb*	0.1	0.3	BR 3 × higher
Atrazine*	0.01	0.02–0.05	BR 2-5 × higher
Chlorpyrifos*	0.01	2.0	BR 200 × higher
Paraquat*	0.02	0.1	BR 5 × higher
Imidacloprid*	0.05	0.5	BR 10 × higher
Tebuconazole	0.05	0.2	BR 4 × higher
Lambda-cyhalotrin	0.02	0.2	BR 10 × higher
Fipronil*	0.005	0.02–0.05	BR 4-10 × higher
Clomazone	0.05	0.2	BR 4 × higher
Diquat*	0.02	0.05	BR 2.5 × higher

*Active substance not approved in the EU (MRL retained only for imports)

Maximum Residue Limits: regulatory asymmetries

Maximum Residue Limits established under EU Regulation 396/2005 represent the legal thresholds for pesticide residues in food and feed. Analysis of MRL disparities between the EU and Brazil reveals significant asymmetries with implications for import safety assurance (Barosso *et al.* 2025; Hoffmans *et al.* 2025; Martins and Burnquist 2025). For substances banned in the EU (chlorothalonil, atrazine, chlorpyrifos, imidacloprid, paraquat), the EU applies default MRLs at the limit of analytical detection (typically 0.01 mg/kg), while these substances remain in active use in Brazil with substantially higher MRLs. The 50-fold difference for chlorothalonil and 200-fold difference for chlorpyrifos in citrus illustrate the challenge of ensuring regulatory equivalence when production practices differ fundamentally (Tab. 10).

For substances banned in the EU, default MRLs at the limit of analytical detection apply, whereas higher MRLs are permitted in exporting countries (Regulation EC No 396/2005; OECD 2017, 2021). While MRLs differ substantially between regions, exported products must comply with EU MRL standards; thus, differences do not constitute a direct competitive advantage but may pose challenges for monitoring and enforcement. In this context, the interpretation of MRL disparities has been refined to avoid suggesting a direct competitive advantage for exporting countries. It is important to emphasize that all products placed on the EU market must comply with EU MRL requirements, regardless of the regulatory framework in the country of origin. However, differences in MRL regimes reflect underlying differences in production systems and pesticide use patterns, which may complicate residue monitoring, analytical verification, and enforcement of compliance at the import stage (OECD 2017, 2021; Hoffmans *et al.* 2025). This perspective provides a more balanced and accurate interpretation of the trade implications associated with regulatory asymmetries.

Summary of active substance availability

Table 11 presents a comparative overview of the availability of active substances for soybean plant protection products (PPPs) in Poland and Mercosur countries. The data reveal a pronounced asymmetry in access to

Table 11. Summary comparison of active substance availability for soybean protection: Poland vs. Mercosur (Source: author's own elaboration based on HOMOLOGA 2025)

PPP Category	Poland	Mercosur	Ratio
Herbicides (chemical)	16	96	1 : 6
Fungicides (chemical)	5	96	1 : 19
Fungicides (biological)	2	104	1 : 52
Insecticides (chemical)	2	94	1 : 47
Insecticides (biological)	3	9	1 : 3

crop protection tools between the two regions. Across all PPP categories, producers in Mercosur benefit from a substantially broader portfolio of authorized active substances than those available in Poland. The disparity is particularly acute for biological fungicides, where Mercosur has access to more than 50 times as many active substances as Poland (104 vs. 2). Similarly, large gaps are observed for chemical insecticides (94 vs. 2; ratio 1 : 47) and chemical fungicides (96 vs. 5; ratio 1 : 19), indicating markedly different levels of regulatory permissiveness and technological availability.

The biological control paradox

The 52 : 1 disparity in biological fungicide strains between Mercosur (104) and Poland (2) presents a striking paradox. The European Union has explicitly prioritized biological alternatives through the Sustainable Use Directive, Green Deal, and Farm to Fork Strategy, yet Mercosur countries – particularly Brazil Insect growth regulators – have achieved far greater diversification of biological control options. This counterintuitive finding merits careful analysis.

Several factors contribute to this paradox. First, Brazil's regulatory system treats each microbial strain as a distinct active substance, enabling rapid expansion of registered options. Second, the scale of Brazilian agriculture creates commercial incentives for biological product development unavailable in smaller markets. Third, the year-round pest pressure in tropical systems drives continuous demand for alternative control methods when chemical options face resistance problems. Fourth, the structure of Mercosur agricultural research – with strong linkages between Embrapa, state research institutions, and commercial developers – accelerates translation from laboratory to field.

It should also be noted that the limited number of biological active substances registered in Poland (currently only two microbial strains) are generally compatible with organic farming systems and align with sustainability objectives. However, their extremely low diversity significantly constrains their practical applicability in both conventional and organic soybean production. This limitation reduces flexibility in disease management, restricts the possibility of combining or rotating biological agents, and ultimately diminishes the effectiveness of biological control strategies under field conditions.

The implications for EU policy are significant. Despite regulatory frameworks designed to promote biological alternatives, practical implementation has not delivered the diversification achieved in Mercosur. Previous studies have identified regulatory complexity, lengthy approval procedures, and high data requirements as key bottlenecks limiting the development and adoption of biological plant protection products in the EU (Balog *et al.* 2017; van Lenteren *et al.* 2018). Accelerating EU registration procedures for biological PPPs, perhaps through mutual recognition agreements or expedited review pathways, could address this gap while advancing sustainability objectives.

Implications for the EU–Mercosur Partnership Agreement

The regulatory asymmetries documented in this study have profound implications for the EU-Mercosur Partnership Agreement finalized in December 2024:

Competitive disadvantage: European soybean producers operate with a fraction of the crop protection tools available to Mercosur counterparts. The 6-fold to 52-fold differences in active substance availability translate into higher production costs, reduced yield potential, and limited capacity to respond to emerging pest and disease pressures. Under tariff liberalization, this asymmetry may accelerate the structural decline of European protein crop production.

Food safety concerns: Approximately 100 active substances used in Mercosur soybean production are not approved for use in the EU, with many explicitly banned due to health or environmental concerns. While imported products must comply with EU Maximum Residue Limits, the use of substances with MRLs 50–200 times higher in Brazil raises questions about effective import surveillance and enforcement capacity.

Structural dependency: The EU imports over 50% of its soybean and soybean meal requirements from Mercosur countries, creating a fundamental dependency with limited short-term alternatives. This dependency constrains the EU's ability to impose stringent import standards without risking supply disruption to the livestock sector.

Regulatory coherence: The simultaneous pursuit of pesticide reduction under the Green Deal and trade liberalization with regions maintaining broader pesticide portfolios creates internal policy tension. Addressing this tension requires either strengthened import controls (potentially facing World Trade Organization (WTO) challenges) or acceptance of asymmetric competitive conditions.

Discussion, conclusions and recommendations

This study demonstrates that regulatory differences in the authorization of plant protection products translate directly into asymmetries in pest management capacity between the European Union and Mercosur countries (Ambroziak *et al.* 2025). From a plant protection perspective, the observed disparities in the number of authorized active substances, diversity of modes of action, and availability of biological control agents have practical implications for resistance management, yield stability, and production resilience in soybean cultivation.

In the European Union, the progressive reduction in authorized chemical active substances has narrowed the spectrum of available tools for soybean protection. While this approach reflects precautionary regulatory objectives, it also constrains the practical implementation of integrated pest management, particularly where alternative modes of action are limited. The restricted availability of herbicides and insecticides increases the risk of resistance development, a phenomenon already documented for several key weed and insect species in European arable systems. This is consistent with broader evidence indicating that reduced diversity of modes of action is a primary driver of resistance evolution, particularly in simplified production systems (Norsworthy *et al*. 2012; Hicks *et al*. 2018; Hawkins *et al*. 2019).

By contrast, Mercosur production systems operate with substantially broader plant protection portfolios, allowing for diversified control strategies and systematic rotation of modes of action. This is particularly relevant for the management of Asian soybean rust, where intensive fungicide programs and access to multiple chemical classes are essential to delay resistance development. The extensive registration of biological fungicides at strain level further enhances the flexibility of disease management strategies in South American soybean production.

The pronounced disparity in biological control availability represents a regulatory bottleneck rather than a technological limitation in the EU context. Despite strong policy support for biological plant protection products, the limited number of authorized microbial strains constrains their practical use in soybean cultivation (Bueno *et al*. 2023). Accelerated and harmonized registration pathways for low-risk biological agents could therefore play a key role in strengthening EU plant protection systems while remaining consistent with sustainability objectives.

Overall, the findings indicate that plant protection considerations should be more explicitly integrated into assessments of trade agreements involving agricultural commodities. Regulatory asymmetries in pesticide availability not only affect competitiveness but also shape phytosanitary risk management and long-term sustainability of crop production systems.

Recent policy developments at the EU level further reinforce the relevance of these findings. The Food and Feed Omnibus package adopted in December 2025 introduces measures aimed at accelerating approval procedures for biological plant protection products, thereby addressing one of the key regulatory bottlenecks identified in this study. These changes are closely aligned with broader EU strategic objectives, including the European Green Deal and the Farm to Fork Strategy, which prioritize the reduction of chemical pesticide use and the promotion of sustainable alternatives. If effectively implemented, the revised regulatory framework may contribute to reducing the current disparities in the availability of biological control solutions between the EU and Mercosur countries, strengthening integrated pest management capacity while maintaining high standards of environmental and human health protection.

This comparative analysis demonstrates that substantial regulatory asymmetries exist between the European Union and Mercosur countries in the availability of plant protection products for soybean cultivation. These differences extend across all major categories of crop protection, including herbicides, fungicides, insecticides, and biological control agents, and they directly influence pest management capacity and resistance risk.

In Brazil, the approval status of pesticide-active ingredients is very discrepant compared to other agricultural countries. Moreover, the duality of benefits and risks of pesticide application creates an economic and toxicological conflict (Souza *et al*. 2023). From a plant protection perspective, the limited spectrum of authorized active substances in the EU constrains the implementation of diversified and resistance-aware management strategies. In soybean production, where effective control of weeds, fungal diseases, and insect pests depends on access to multiple modes of action, such constraints may reduce production resilience and increase vulnerability to emerging phytosanitary threats.

The policy implications of these findings have been further expanded in light of the ongoing European debate on trade and regulatory alignment. In particular, increasing attention is being paid to the concept of "mirror clauses", which would require imported agricultural products to comply with standards equivalent to those applied within the EU. In parallel, discussions include the potential lowering of MRLs for non-approved substances to the level of technical zero, as well as strengthening border control systems, for example through a substantial increase in inspection frequency (e.g., by 50%). These proposals are actively debated at the level of the European Commission and Member States, including countries such as France, reflecting growing political pressure to ensure consistency between domestic regulatory standards and import requirements. Taken together, these developments indicate that regulatory asymmetries in plant protection are becoming a central issue in EU trade policy, with potential implications for market access, compliance costs, and the future structure of agri-food supply chains.

The practical consequences of these regulatory constraints are, however, context-dependent and vary across pest groups and management scenarios. In some cases, effective control remains feasible despite a limited spectrum of authorized substances. For example, weed management in soybean can still be maintained under moderate pressure through reliance on a reduced set of herbicides, such as ACCase inhibitors, when complemented by appropriate agronomic practices including crop rotation, mechanical control, and optimization of sowing systems. In contrast, other situations represent critical limitations, particularly where effective control depends on access to multiple modes of action. This is exemplified by the management of Asian soybean rust (*Phakopsora pachyrhizi*), a highly destructive disease requiring intensive fungicide programs and systematic rotation of active ingredients to delay resistance development. The restricted fungicide portfolio available in the EU significantly constrains both resistance management and disease control capacity in this context. These contrasting examples illustrate that the implications of regulatory restrictions are not uniform, but range from manageable to highly limiting depending on the biological characteristics of the target organism and the availability of complementary management strategies.

The markedly broader availability of biological fungicides in Mercosur countries highlights that regulatory processes, rather than technological limitations, are a key factor shaping the practical adoption of biological control (OECD 2017, 2021; EFSA, multiple years). Streamlining authorization procedures for low-risk biological agents could, therefore, strengthen integrated pest management in the EU while remaining consistent with sustainability objectives.

Overall, the findings underline the importance of explicitly considering plant protection systems in the context of expanding international trade in agricultural commodities. Future research should focus on the long-term implications of regulatory asymmetries for resistance evolution, crop health, and the sustainability of soybean production systems under increasingly interconnected global markets, with particular emphasis on resistance dynamics and Integrated Pest Management (IPM) robustness (Cerdeira *et al.* 2011; Heap 2025; FRAC 2023; IRAC 2023).

This comprehensive analysis reveals fundamental structural asymmetries in crop protection systems between the European Union and Mercosur that have significant implications for agricultural trade, food safety, and production sustainability. The documented disparities – ranging from 6 : 1 for herbicides to 52 : 1 for biological fungicides – represent not merely quantitative differences but fundamentally different regulatory philosophies and production paradigms. Importantly, the observed regulatory asymmetries should also be interpreted in light of the underlying risk rationale guiding pesticide authorization decisions in the European Union. A substantial proportion of active substances no longer approved in the EU have been withdrawn due to well-documented concerns related to human health (including carcinogenicity and endocrine disruption), environmental persistence and bioaccumulation, as well as toxicity to non-target organisms such as pollinators and aquatic species. This reflects the fundamentally hazard-based nature of the EU regulatory framework, in contrast to the predominantly risk-based approaches applied in Mercosur countries. This distinction has been widely discussed in the literature on EU risk governance, where the precautionary principle plays a central role in regulatory decision-making (European Commission 2020), particularly in the context of plant protection product risk assessment frameworks. While this precautionary paradigm contributes to higher levels of health and environmental protection, it simultaneously reduces the diversity of available modes of action, thereby influencing pest management flexibility and resistance dynamics. Consequently, the differences identified in this study should not be interpreted solely as disparities in regulatory efficiency or market access, but rather as outcomes of distinct regulatory philosophies that balance agricultural productivity, environmental protection, and public health in different ways. This perspective enhances the policy relevance of the present analysis, particularly in the context of ongoing evolution of EU pesticide legislation and its implications for international trade.

Based on these findings, we propose the following policy recommendations:

Enforceable mirror clauses: The EU should negotiate enforceable provisions requiring that imported agricultural products meet equivalent production standards, particularly regarding the use of active substances banned in the EU. While such provisions face WTO scrutiny, they represent the most direct approach to ensuring regulatory coherence.

Enhanced import surveillance: Expanded residue testing programs should specifically target substances banned in the EU but permitted in exporting countries. Current sampling rates may be insufficient to ensure compliance given the scale of Mercosur imports and the breadth of substances in use.

Compensatory mechanisms: Recognition that EU producers face structurally higher costs due to regulatory restrictions should inform support mechanisms under the Common Agricultural Policy, potentially including enhanced direct payments for protein crop production.

Accelerated biological PPP registration: The paradox of Mercosur's greater biological control diversification should prompt review of EU registration procedures. Expedited pathways for low-risk biological products could advance sustainability objectives while expanding the crop protection toolkit.

Strategic protein security investment: Reducing structural dependency on Mercosur soybean imports requires long-term investment in European protein crop production, including dedicated research programs, breeding initiatives, and market development support.

Continuous monitoring: Establishment of systematic market monitoring mechanisms to track the evolution of competitive conditions post-agreement, with defined safeguard activation thresholds.

The EU–Mercosur Partnership Agreement represents a historic development in global agricultural trade. Ensuring that this agreement delivers mutual benefits while protecting European production standards, food safety, and environmental sustainability requires clear-eyed assessment of the asymmetries documented in this study and policy responses adequate to address them.

References

Ambroziak Ł., Bułkowska M., Szczepaniak I. 2025. Agricultural production potential in the EU and Mercosur countries: A comparative analysis. Sustainability 17: 11135. DOI: https://doi.org/10.3390/su172411135

Cerdeira A.L., Gazziero D.L.P., Duke S.O., Matallo M.B. 2011. Agricultural impacts of glyphosate-resistant soybean cultivation in South America. Journal of Agricultural and Food Chemistry 59 (11): 5799–5807. DOI: 10.1021/jf102652y

Balog A., Hartel T., Loxdale H.D., Wilson K. 2017. Differences in the progress of the biopesticide revolution between the EU and other major crop-growing regions. Pest Management Science 73 (11): 2203–2208. DOI: https://doi.org/10.1002/ps.4596

Bombardi L.M. 2019. A Geography of agrotoxins use in Brazil and its relations to the European Union, Universidade de São Paulo. Faculdade de Filosofia, Letras e Ciências Humanas, 266 pp. DOI: https://doi.org/10.11606/9788575063590

Bueno A.d.F., Paula-Moraes S., Gazzoni D.L., Pomari-Fernandez A. 2013. Economic thresholds in soybean-integrated pest management: old concepts, current adoption, and adequacy. Neotropical Entomology 42 (5). DOI:10.1007/s13744-013-0167-8

Bueno A.d.F., Sutil W.P., Jahnke S.M., Carvalho G.A., Cingolani M.F., Colmenarez Y.C., Corniani N. 2023. Biological control as part of the soybean integrated pest management (IPM): Potential and Challenges. Agronomy 13 (10): 2532. DOI: https://doi.org/10.3390/agronomy13102532

Bułkowska M., Ambroziak Ł. 2025. Assessment of competitiveness and complementarity in agri-food trade between the European Union and Mercosur Countries. Agriculture 15: 2504. DOI: https://doi.org/10.3390/ agriculture15232504

de Oliveira S.E.M.C., Visentin J.C., Pavani B.F., Branco P.D., de Maria M., Loyola R. 2024. The European Union – Mercosur Free Trade Agreement as a tool for environmentally sustainable land use governance. Environmental Science & Policy 161: 103875. DOI: https://doi.org/10.1016/j.envsci.2024.103875

European Commission 2020. Farm to fork strategy – for a fair, healthy and environmentally-friendly food system. Available on: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381 [Accessed: 31.01.2026]

European Commission 2024. EU–Mercosur Trade Agreement: Political agreement reached; Press Release, December 2024

European Food Safety Authority (EFSA). Peer review of pesticide risk assessment of active substances under Regulation (EC) No 1107/2009. EFSA Journal (multiple years) [Accessed: 31.01.2026]

FAOSTAT (Food and Agriculture Organization of the United Nations) 2024. Pesticides Use Database 2024. Rome, Italy

FRAC (Fungicide Resistance Action Committee) 2025. FRAC Code List 2025: Fungal control agents sorted by cross-resistance pattern and mode of action (including coding for FRAC Groups on product labels) [Accessed: 8.02.2026]

Gohin A., Matthews A. 2025. The European Union–Mercosur Association Agreement: Implications for the EU Livestock Sector. Journal of Agricultural Economics 77 (1): 25–35. DOI: 10.1111/1477-9552.70010

Hartman G.L., Rupe J.C., Sikora E.J., Domier L.L., Davis J.A., Steffey K.L. (eds.). 2015. Compendium of Soybean Diseases and Pests. 5th ed. APS Press; St. Paul, MN, USA, 201 pp.

Heap I. 2025. The International Survey of Herbicide Resistant Weeds. Online database. Available on: https://www.weedscience.org [Accessed: 31.01.2026]

Hawkins N.J., Bass C., Dixon A., Neve P. 2019. The evolutionary origins of pesticide resistance. Biological Reviews 94: 135–155. DOI: https://doi.org/10.1111/brv.12440

Hicks H.L., Comont D., Coutts S.R., Crook L., Hull R., Norris K., Neve P., Childs D.Z., Freckleton R.P. 2018. The factors driving evolved herbicide resistance at a national scale. Nature Ecology & Evolution 2 (3): 529–536. DOI: https://doi.org/10.1038/s41559-018-0470-1

Hoffmans Y., Safitri R., Mol H., Bikker P. 2025. Overview of pesticides authorised in maize and soybean grown outside the EU: Authorised active substances for use in plant protection products in maize and soybean in Brazil, Ukraine and the United States. (WFSR-report; No. 2025.007). Wageningen Food Safety Research. DOI: https://doi.org/10.18174/693520

HOMOLOGA 2025. The global crop protection database. Available on: www.homologa.com [Accessed: 30.12.2025]

HRAC (Herbicide Resistance Action Committee) 2026. 2026 HRAC Global Herbicide MoA Classification. Available on: https://hracglobal.com/tools/2026-hrac-global-herbicide-moa-classification [Accessed: 8.02.2026]

IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis) 2025. Relatórios de Comercialização de Agrotóxicos 2022–2024. Brasília, Brazil. https://www.gov.br/ibama/pt-br/assuntos/quimicos-e-biologicos/agrotoxicos/relatorios-de-comercializacao-de-agrotoxicos [Accessed: 8.02.2026]

IRAC (The Insecticide Resistance Action Committee) 2026. IRAC Mode of action classification scheme. Edition 11.5. Available on: IRAC-MoA_brochure_Ed11.5_4Feb26-1770200864.pdf [Accessed: 8.02.2026]

Korbas M., Paradowski A., Węgorek P., Jajor E., Horoszkiewicz--Janka J., Zamojska J., Danielewicz J., Czyczewski M., Dworzańska D. **2017.** Vademecum środków ochrony roślin. Wydawnictwo Agronom, Poznań, 672 pp.

Lamichhane J.R. 2017. Pesticide use and risk reduction in European farming systems with IPM: An introduction to the special issue. Crop Protection. DOI: 10.1016/j.cropro.2017.01.017

Lucas J.A., Hawkins N.J., Fraaije B.A. 2014. The evolution of fungicide resistance. Advances in Applied Microbiology 90: 29–92. DOI: https://doi.org/10.1016/bs.aambs.2014.09.001

Martins M.M.V., Burnquist H.L. 2025. Maximum Residues Limits (MRLs) of pesticide and international trade dynamics to Mercosur and EU. Available on: https://www.anpec.org.br/encontro/2024/submissao/files_I/i11-6ec02f-3d77a3df54eff865918d251745.pdf?utm_source=chatgpt.com [Accessed: 31.01.2026]

Norsworthy J.K., Ward S.M., Shaw D.R., Llewellyn R.S., Nichols R.L., Webster T.M., Bradley K.W., Frisvold G., Powles S.B., Burgos N.R., Witt W.W., Barrett M. 2012. Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Science 60 (SP1): 31–62. DOI: 10.1614/WS-D-11-00155.1

OECD (Organisation for Economic Co-operation and Deve lopment) 2017. International regulatory co-operation and trade: Understanding the trade costs of regulatory divergence and the remedies. OECD Publishing, Paris, France. DOI: https://doi.org/10.1787/9789264275942-en

OECD (Organisation for Economic Co-operation and Development) 2021. International Regulatory Co-operation, OECD Best Practice Principles for Regulatory Policy, OECD Publishing, Paris. DOI: https://doi.org/10.1787/5b28b589-en.omic

Oliveira R.C., Raetano C.G., Junior J.D., Carvalho F.K. 2017. Integrated management of soybean pests: The example of Brazil. Outlooks on Pest Management 28 (4): 149–153. DOI:10.1564/v28_aug_02

Perobelli J.E. 2025. Pesticides and public health: discussing risks in Brazilian agro-industrial growth. Frontiers in Toxicology 7: 1442801. DOI: 10.3389/ftox.2025.1442801

Procópio S.d.O., Barizon R.R.M., Pazianotto R.A.A., Morandi M.A.B., Braz G.B.P. 2024. Impacts of weed resistance to glyphosate on herbicide commercialization in Brazil. Agriculture 14: 2315. DOI: https://doi.org/10.3390/agriculture14122315

Regulation (EC) No 396/2005 of the European Parliament and of the Council on maximum residue levels of pesticides in or on food and feed of plant and animal origin. Official Journal of the European Union 2005, L70: 1–16.

Souza M.C.O., Cruz J.C., Cesila C.A., Gonzalez N., Rocha B.A., Adeyemi J.A., Nadal A., Nadal B., Domingo J.L., Barbosa F. 2023. Recent trends in pesticides in crops: A critical review of the duality of risks-benefits and the Brazilian legislation issue. Environmental Research 228: 115811. DOI: https://doi.org/10.1016/j.envres.2023.115811

Sparks T.C., Nauen R. 2015. IRAC: Mode of action classification and insecticide resistance management. Pesticide Biochemistry and Physiology 121: 122–128. DOI: https://doi.org/10.1016/j.pestbp.2014.11.014

Stankiewicz-Kosyl M., Synowiec A., Haliniarz M., Wenda-Piesik A., Domaradzki K., Parylak D., Wrochna M., Pytlarz E., Gala-Czekaj D., Marczewska-Kolasa K., Marcinkowska K., Praczyk T. 2020. Herbicide resistance and management options of *Papaver rhoeas* L. and *Centaurea cyanus* L. in Europe: A Review. Agronomy 10: 874–896. DOI: 10.3390/agronomy10060874

Stankiewicz-Kosyl M., Haliniarz M., Wrochna M., Synowiec A., Wenda-Piesik A., Tendziagolska E., Sobolewska M., Domaradzki K., Skrzypczak G., Łykowski W., Krysiak M., Bednarczyk M., Marcinkowska K. 2021. Herbicide resistance of *Centaurea cyanus* L. in Poland in the context of its management. Agronomy 11: 1954. DOI: 10.3390/agronomy11101954

Stankiewicz-Kosyl M., Haliniarz M., Wrochna M., Obrępalska-Stęplowska A., Kuc P., Łukasz J., Wińska-Krysiak M., Wrzesińska-Krupa B, Puła J., Podsiadło C, Domaradzki K., Piekarczyk M., Bednarczyk M., Marcinkowska K. 2023. Occurrence and mechanism of *Papaver rhoeas* ALS inhibitors resistance in Poland. Agriculture 13 (1): 82. DOI: https://doi.org/10.3390/agriculture13010082

Strażyński P., Mrówczyński M., Kierzek R. 2025. Availability constraints of plant protection products in Polish winter cereal production – A Post–EU accession perspective. Journal of Plant Protection Research 65 (4). DOI: 10.24425/jppr.2025.156889

van Lenteren J.C., Bolckmans K., Köhl J., Ravensberg W.J., Urbaneja A. 2018. Biological control using invertebrates and microorganisms: plenty of new opportunities. BioControl 63 (1): 39–59. DOI: https://doi.org/10.1007/s10526-017-9801-4

Yorinori J.T., Paiva W.M., Frederick R.D., Costamilan L.M., Bertagnolli P.F., Hartman G.E., Godoy C.V., Nunes J.Jr. 2005. Epidemics of soybean rust (*Phakopsora pachyrhizi*) in Brazil and Paraguay from 2001 to 2003. Plant Disease 89 (6): 675–677. DOI: 10.1094/PD-89-0675