The Chemical Training of Agrarian Specialists: From the Chemicalization of Agriculture to Green Technologies

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Abstract: The impact of agricultural production on the ecological condition of vast territories is of concern to the entire world community. Therefore, the concept of sustainable development should become the basis for the training of agricultural specialists. This article examines the transformation of the system of chemical training of agricultural students in Russia, taking into account the transition to the concept of sustainable development. The study of the history of the development of chemical training of agricultural specialists in Russia helped us to see the causes of the current crisis and highlights what should be preserved. The analysis of the modern needs of the agro-industrial complex made it possible to identify ways to modernize the system of teaching chemical disciplines in agricultural universities. As a result, the main trends of modernization of chemical training of future agricultural specialists in the context of the concept of sustainable development are identified. The chemical competencies of specialists of the agro-industrial sector working in the field of production, processing, and quality control of agricultural products are differentiated. The conditions of their formation are determined, and the effectiveness of the application of the principles of green chemistry for the formation of selected competencies is shown. The theoretical significance of the research is the development of the concept of ecological chemical education (green chemistry) for agricultural education. The practical significance of this work lies in the development of practical examples of the application of the principles of green chemistry in the educational process of an agrarian university. The originality of this research lies in determining the pedagogical conditions for the formation of chemical competencies of agricultural specialists in the context of orientation to the concept of sustainable development.

Keywords: agricultural education; chemical training; ecological agriculture; green chemistry; sustainable development; history of chemical education

1. Introduction

At present, the attitude toward natural resources is changing the paradigm. Many teachers and researchers from all over the world are studying ecological education policies, such as Glackin and King [1], Payne [2], Reid [3], Rickinson and Mackenzie [4], Bylund [5], and many others. Mulder and Kupper [6] and Liberloo et al. [7] considered the issues related to the ecologization of agrarian education. Grigoryeva [8], Liberloo et al. [7], Koutsouris [9], Vic et al. [10], Lambrechts et al. [11], and MacGregor [12] have researched issues in creating a new agrarian education based on the concept of sustainable development. Other issues that interfere with the development of ecological agriculture are the topics, for example, of papers by Vermunt [13] and Dorin [14]. Emendu [15] and Fanzo et al. [16] have proven the crucial role of chemical knowledge in solving food-related and other problems. Some researchers have focused on improving the education process with regard to the chemical training of agrarian university students [17–20].
Green chemistry education (GCE) is currently being actively developed in many countries. It is a trending topic of research in books [21] and scientific papers [22–25]. It is most often considered in relation to economy, management, industry, systemic approach, education technologies, and specific branches of chemistry (e.g., catalytic processes). The current paper is devoted to the chemical training system in agricultural universities, taking into account its specificity, especially as far as green chemistry is concerned.

This represents a problem in the Russian educational system that has not been researched enough. Tarasova et al. [26] present a review of all the Russian organizations dealing with sustainable and environmental chemical training. According to them, despite the necessity for sustainable chemical training in Russia, as confirmed by statistical data and governmental initiatives, this issue still needs much work. A small think tank of researchers from different Russian universities (in particular, from Moscow Lomonosov State University) is actively researching this field. This paper describes the ways in which these universities are introducing the principles of “green chemistry” in the educational process of students from chemical faculties. Lunin et al. [27] present and analyze the summary of the master’s degree program “Chemistry for the benefit of sustainable development”, which is currently being implemented at Moscow Lomonosov State University. Kustov and Beletskaya [28] illustrate examples of the application of the principles of green chemistry in the educational process of students from the chemical faculty of the same university. Particular attention is devoted to catalytic processes. Lokteva [29] studies the motivation in students from Moscow Lomonosov State University when applying the approaches of “green chemistry” in their research. To promote the principles of sustainable development among youth, Lokteva suggests including exercises on “green chemistry” in the skills contests held at the university. She also highlights how online training in the field of green chemistry is particularly effective in vast countries such as Russia.

Thus, we can see that issues regarding the ecologization of the chemical training are not being elaborated as far as students from agricultural universities are concerned. However, adequate chemical training is necessary for future agrarian specialists to apply the principles of green economy. This task is of crucial importance for teachers working at agrarian universities all over the world. Let us consider research conducted by teachers from Russian agrarian universities.

Russia is a vast country with a well-developed agricultural system and an important exporter of agricultural commodities [30]. Historically, Russia has always been an agricultural country. Nonetheless, Russian agriculture has had to face different crises over the centuries, but it always found a way to recover. Agrarian education played a key role in this respect. Nowadays, the Russian system of higher agrarian education includes 54 universities and more than 30 agricultural faculties and institutes in non-specialized universities. The number of students accounts for more than 300,000 people every year. Russian higher agrarian education has a rich history, which brought great scientific achievement in the fields of agrochemistry and chemistry as well. The transformation of the chemical training system for Russian agrarian specialists is a rich experience that can be applied for great numbers of students and thus can be interesting for other countries as well.

One of the first tasks that arises when implementing ecological farming is the educational work and training of personnel who can competently understand, elaborate, and implement their ideas in agriculture. Even though one of the principles of ecological farming is the restriction or complete exclusion of the use of agrochemicals that are aggressive towards the environment, such as pesticides (herbicides, insecticides, rodenticides, and fungicides) and chemical fertilizers, the importance of the training of future specialists in this field does not diminish. The emphasis and required chemical competencies have changed. The importance of some sections of chemical disciplines is enhanced or reduced. The chemical training of specialists for current ecological farming requires revisions and changes.

To implement the conception of sustainable development in the agro-industrial sector, corresponding specialists are needed. Having different levels of education (undergraduate,
graduate, and postgraduate), they should be able to deeply understand the processes and to identify highly technological approaches to solve the current ecological problems and prevent possible ones in the future.

The components of the pedagogical system need to be systematized and structurized when implementing the bases of green chemistry in the educational process as regards different chemical disciplines taught to students at an agrarian university. This substantiates the crucial importance of the current research.

The purpose of the study was to identify ways to modernize the system of chemical training of students at agricultural universities in the context of the concept of sustainable development.

This process included the following tasks:

- Analysis of the century-and-a-half history of chemical training in Russian agrarian universities to determine the causes of the current crisis and to identify the “strengths” that should be preserved;
- Identifying the main trends in the modernization of chemical training;
- Examples of the implementation of chemical training systems based on the concept of sustainable development.

2. Materials and Methods

The philosophical and psychological conceptions of professional activity are the methodological bases of the research, along with different methodological approaches, such as systemic, competence-oriented, pragmatic, and acmeological, used in education. In particular, we referred to specialist modeling theory (V.S. Gershunskii, A.A. Rean, and N.F. Talyzina), theoretical foundations for the formation of the structure and content of professional education (Yu.K. Babanskii, V.P. Bespalko, V.S. Lednev, I.Ya. Lerner, M. N. Skatkin, and others), and the general concept of chemical training and teaching of chemical disciplines (M. V. Gorskii, O. S. Zaitsev, A. A. Makarenya, M. S. Pak, V. V. Sorokin, N. N. Surtaeva, G. M. Chernobelskaya, and others).

The concept of sustainable development and the principles of green chemistry are the methodological background of this research. In particular, we referred to the position of G. Harlem Brundtland, which determines the tasks of sustainable development, along with the principles of green chemistry formulated by Anastas and Warner.

The results of this research have been introduced at the Russian State Agrarian University—Moscow Timiryazev Agricultural Academy. To assess the effectiveness of the implemented system, the control and experimental groups were tested to determine the level of competence in the field of green chemistry. When evaluating the results of the study, we used statistical methods, and the criterion $\chi^2$ was used to determine the reliability of the differences.

3. Results

3.1. How Was the Chemical Training System Formed in Russian Agrarian Universities?

The history of the systematic chemical training of agrarian students in Russia dates back more than 150 years. Some key figures led the way for the development of the chemical training of agrarian specialists in Russia in the XIX century. They were the disciples of European scholars who influenced their activities. In particular, two professors laid the foundation for the chemical training system at the first Russian agrarian university: P.A. Ilyenkov and N.E. Lyaskovskii. They were both students of the famous German chemist Justus von Liebig. Professor E.B. Schöne had studied in Berlin, where he was the apprentice of the famous German scholars Heinrich Rose and Karl Rammelsberg. The German Chemical School has become the basis for chemical training. It had a fundamental and universal nature and included an in-depth study of the basics, a wide application of chemical experiments, and demonstrations of experiments during lectures. The content and methods of chemical disciplines were similar to those taught in traditional, non-specialized
universities. The students studied inorganic, analytical, and organic chemistry, as well as agricultural analysis.

The twentieth century saw the formation of a teaching system suitable for teaching a great number of students. Many agrarian universities have been founded throughout the country. The number of agrarian specialties has increased. The curricula on chemical disciplines were released on a centralized basis for all agrarian universities in the country. This period coincides with the blossoming of intensive agriculture and its chemicalization. The main research trends regarded fertilizers, chemicals for plant protection, farmland improvement, and similar topics. Chemical training of agrarian specialists remains fundamental. Agrochemistry has undergone intensive development. New handbooks and textbooks on chemical disciplines were released, many of which were specially designed for teaching in agrarian universities.

During the second half of the XX century, it became clear that the chemicalization of agriculture and intensive agricultural technologies harmed the environment: toxic agents impoverished and contaminated the soil and polluted the water bodies [31]. Agriculture is no longer safe for human health because of pesticide residues in plant commodities, hormones in animal husbandry products, and similar problems [32]. The nutritional value of the output decreased [33]. The effect of “chemophobia”—the fear of chemicals—emerged in society [34].

All these issues escalated at the beginning of the XXI century. The teaching system is characterized by a negative trend, due to which the number of hours devoted to the study of chemical disciplines has been constantly declining. The main cause of this is the economic recession that the country had to face. The number of contact hours (in class) is reduced. This led to a reduction in the share of chemical experiments in the teaching process. The nature of chemical training is no longer fundamental but more superficial. In most agrarian universities, the departments of chemistry are no longer independent and have been integrated with other structural units. Chemical training is reduced to a superficial study of the bases of chemistry. To preserve the quality of education despite the limited number of teaching hours, teachers are using new pedagogic and information technologies. Handbooks and textbooks are constantly being improved. Some of them discuss specialized content issues for agriculture in great detail. In addition, the chemical training of agrarian specialists is facing a crisis with regard to its content. At present, specialists in the agro-industrial sector must be competent in issues related to chemical substances and processes. This has been confirmed by enquiries among employers and specialists in the agro-industrial sector [8].

Thus, we were able to identify the following historical phases in the development of the chemical training system in agrarian universities (Table 1).

Table 1. Phases of the development of the teaching system of chemical disciplines in Russian agrarian universities.

| Development Phases | Key Concepts and Innovations | Content of Chemical Disciplines | Methodological Aspects |
|--------------------|-----------------------------|---------------------------------|------------------------|
| 1. Origin and establishment (1865–1920) | Borrowing of the teaching system from other universities and laboratories and adaptation to their specific goals. This leads to the formation of the classical university system for teaching chemical disciplines. | Classical university courses in inorganic, organic, and analytical chemistry. | Many hours divided between lectures, laboratory practicums, and lectures/demonstrations. Students do not engage in research activities. The chemistry handbooks published in this phase are not specialized for agrarian universities. |
Table 1. Cont.

| Development Phases                  | Key Concepts and Innovations                                                                 | Content of Chemical Disciplines                                                                 | Methodological Aspects                                                                 |
|-------------------------------------|-----------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| 2. Diffusion and chemicalization    | The teaching system aims at educating a great number of students. The curriculum focuses on the chemicalization of agriculture. | The fundamental nature of basic chemical education is preserved. Agrochemistry is flourishing. Fertilizers and pesticides are the main focus. | Programmed control. The chemistry handbooks are now specialized for agrarian specialties. Students are more engaged in research activities. |
| (1921–1990)                         |                                                                                               |                                                                                               |                                                                                       |
| 3. Reduction of chemical training   | The ecological crisis leads to “chemophobia”. The economic crisis leads to a search for the least possible expenses for education. Shift from a knowledge-based approach to a competency-based one. | Chemical training becomes weak and superficial.                                                | The number of hours devoted to the study of chemical disciplines is reduced.           |
| (1991–2005)                         |                                                                                               |                                                                                               |                                                                                       |
| 4. Current phase                    | Orientation towards the concept of sustainable development and application of the principles of green chemistry. | Chemical disciplines interact with ecology. The role of physicochemical analytic methods increases. | Active use of project-based learning.                                                  |
| (since 2006)                        |                                                                                               |                                                                                               |                                                                                       |

3.2. In Which Direction Is the System of Students’ Chemical Training in Russian Agrarian Universities Developing at Present?

The last decade has witnessed active attempts at solving problems related to product safety and the preservation of territorial ecological well-being. The priorities of sustainable development, increasing competitiveness, and scientifically based greening of the country’s agro-industry outlined by the President and the Government of Russia (Decree of the President of the Russian Federation of 1 December 2016, No. 642; Strategy for the development of agricultural education in the Russian Federation until 2030) actualize the priority tasks of development and improving the educational and methodological base of the step-by-step diversified training of high-quality agro-industry specialists of three qualification levels (bachelor’s, master’s, and candidates of science) in agricultural universities of Russia, capable and ready to reach the set goals.

The monitoring of the production quality was enhanced. Russia’s accession to international unions, such as BRICS (China, Russia, Brazil, India, and South Africa, 2006) and the Eurasian Customs Union (Armenia, Belarus, Kazakhstan, Kyrgyzstan, and Russia, 2014), resulted in significant changes in the sphere of technical regulation of agricultural products. In turn, this creates a need for specialists in the agrobusiness who are proficient in methods of analysis.

Organic farming is being developed. On 1 January 2020, Federal Law No. 280-FZ “On Organic Products and on Amendments to Certain Legislative Acts of the Russian Federation” came into force. A paper by Grigoryeva and Belopukhov [35] presented the aspects of personnel’s chemical training for organic farming. Attempts to implement green chemistry principles and green economy into agriculture are being made [36,37].

The chemical education of agrarian specialists requires modernization [38], which is confirmed by surveys conducted among working specialists [8]. There is a need to train specialists in the agro-industrial sector who possess the most modern methods of quality control and safety of agricultural products as well as specialists in the field of agro-ecological control.

3.3. Outlook Basis and Objectives

The 12 widely known principles of green chemistry were formulated by Anastas and Warner [39] and Anastas et al. [40,41]. They may be used in any production that is connected with the use of chemical processes. Most of these may be implemented in agriculture.

The main objectives of current eco-oriented farming are:
1. Providing consumers with ecologically safe top-quality agricultural production;
2. Preserving the ecological well-being of farmlands and surrounding areas and maintaining and improving soil fertility.

The abovementioned objectives create a list of tasks for farmers. Further, we will pay close attention to the group of tasks that require knowledge of chemistry to be solved:

(1) Diagnostics of characteristics, soil fertility, and identification of scarce elements, as well as elaboration of plans to improve soil quality. This criterion is being implemented both in intensive farming and in emerging evaluation methodologies of farming enterprises for organic production [42,43];
(2) Monitoring of soil conditions. With long-term use, soil fertility should not decrease. This is a key criterion for modern sustainable agricultural enterprises. Long-term observations of the soil conditions are necessary;
(3) Processing of agricultural products while applying methods that ensure environmental integrity and preserve the defining qualitative characteristics of products at all stages of the production chain;
(4) Product quality control proof of the absence of toxicants and proof of the presence of the necessary quantities of trace elements, vitamins, and other valuable nutrients for a given type of product [44];
(5) Solving the problem of agricultural waste utilization.

3.4. Main Directions of the Modernization of Future Agricultural Specialists’ Chemical Training

Our research has shown that chemical training is different for three groups of professional areas (three groups of specialties):

(1) Farm specialists working with soil and plants (agronomists, soil scientists, and ecologists);
(2) Specialists involved in product processing (food production technologists, technologists of medicinal and essential oil raw materials, biotechnologists, etc.);
(3) Specialists working in laboratories for the quality control of raw materials and finished products.

The analysis of specialists’ labor functions, goals, and tasks of ecology, surveys of working specialists [8], and the cooperation experience of the RSAU-MTAA Department of Chemistry with agricultural farms showed the most important chemical components of education: (1) basic chemical training that allows us to understand and manage the dynamic processes occurring in the agrosphere; (2) knowledge of the physicochemical and toxicological properties of modern environmentally friendly agrochemicals; (3) innovative instrumental methods of analysis, which are required to control the quality and safety of raw materials and products, to carry out agrochemical diagnostics of soils and water sources and environmental monitoring to assess the impact of agriculture on soil fertility, to conduct research activities, and to evaluate methods of processing, storage, and packaging. Laboratory specialists must have the required competence to conduct physicochemical determinations of the sample tests. The remaining specialists must know the purpose of the methods and be able to interpret the results of the determinations.

An advanced agricultural enterprise should take care of the preservation of soil fertility in its territories for many years. Therefore, soil analysis should not be performed once. On the contrary, the enterprise should monitor some indicators to assess the impact of long-term agricultural activity on soil conditions. These data are necessary to develop a digital model for the management of the physiological and biochemical processes on the farm to obtain high-quality products [8,42–45].

Thus, it is obvious that for environmentally safe functioning, farms need to interact with research laboratories. Accordingly, in the system of the agricultural sector of our country, there should be specialists from research laboratories who are proficient in the most innovative methods of chemical and physicochemical analysis concerning the objects of the agrosphere.
Specialists working with land (agronomists, soil scientists, and ecologists) should also know the methods for laboratory diagnostics of the objects of the agrosphere but at a different level than laboratory specialists. One of the main professional tasks is to carry out agrotechnical measures aimed at increasing soil fertility and productivity of cultivated crops. To solve this task, farm specialists must understand the purpose of the physical and chemical methods of analysis, make the right choice when ordering certain tests, select the samples of the objects of the agrosphere (soil, water, plants, etc.) to determine the physical and chemical indices, interpret the results of laboratory tests, assess soil fertility, and make recommendations on agrotechnical measures based on the results of the analytical determinations of the physicochemical indices of soil, water, and plants, as well as carry out the necessary calculations and carry out research activities.

To perform these labor functions, when training agrarian specialists, it is vital to pay attention to the formation of basic concepts of the newest methods of chemical and physicochemical analysis, their purpose and the interpretation of their results, and the methods of quantitative information processing. These competencies should be formed in addition to the traditional knowledge of the fundamental sections of chemistry, which is necessary for understanding the foundations of dynamic processes in nature and the technosphere, and the quantitative methods describing chemical processes. Basic chemical training is carried out in the chemical disciplines of a bachelor’s degree and includes different sections such as properties of inorganic and organic substances, chemical and physicochemical phenomena, solutions, pH, Raoult’s laws, osmosis, fundamentals of thermodynamics, chemical equilibrium, chemical kinetics, electrochemistry, phase equilibria, surface science, adsorption, and dispersed systems.

RSAU—MTAA carries out the master’s program “Agroecological management, chemical-toxicological, microbiological analysis, and assessment of agricultural objects”, a profile in the specialty “Agrochemistry and agrosoil science” where one of the basic components is chemical disciplines. In addition to this program, three more master’s programs in similar fields of knowledge are being implemented in Russia: (1) MSc Chemistry of the Environment, Peoples’ Friendship University of Russia (Moscow, Russia); (2) Master in Environmental Chemistry, Chemical Expertise and Environmental Security, Immanuel Kant Baltic Federal University (Kaliningrad, Russia); (3) “Soil and ecological monitoring, protection and rational use of lands”, master’s degree, Perm State Agro-Technological University (Perm, Russia). For such a large country, this is not enough. There are similar programs in other countries: (1) MSc in Sustainable Agriculture and Food Security, Czech University Of Life Sciences Faculty of Agrobiology, Food and Natural Resources; (2) Master in Food Safety and Quality, University of Veterinary Sciences (Brno, Czech Republic); (3) Master in Food Politics and Sustainable Development, European School of Political and Social Sciences (Lille, France); (4) MSc in Food Quality and Safety, University of Bayreuth (Bayreuth, Germany); (5) MA in Environment, Development, and Peace with Specialization in Sustainable Food Systems, University for Peace (Ciudad Colón, Costa Rica); (6) Master of Science in Food Safety and Quality Engineering, University Of Debrecen (Debrecen, Hungary); (7) Master of Science in Sustainable Agriculture and Food Security, Royal Agricultural University (Cirencester, United Kingdom); and others.

The master’s program “Agroecological management, chemical-toxicological, microbiological analysis, and assessment of agricultural objects” has been used for over 10 years and is aimed at training specialists in the field of chemical, biochemical, microbiological, and physicochemical quality control of agricultural products at all stages of the technological scheme of production, storage, and processing. The other competencies of the specialists’ training are to assess the quality of products in terms of the content of toxicants and macro and trace elements, considering the requirements of environmental safety and the features of the qualitative and quantitative composition, to carry out scientific work in the field of quality control and product certification. Graduates of this master’s program worked successfully in the area of their specialty. Most graduates work in enterprises and research institutes, subordinate to the Ministry of Agriculture. Many of them work for different
enterprises in the departments of incoming quality control or the centers of Rosselkhoznadzor (Federal Service for Veterinary and Phytosanitary Surveillance) and Rospotrebnadzor (Federal Service for Surveillance on Consumer Rights Protection and Human Well-being).

Table 2 summarizes the information on the methods for forming the necessary chemical competencies for various specialists in the agro-industrial sector.

In addition, the Department of Chemistry of RSAU—MTAA provides further education programs such as “Biological and instrumental methods of quality control of consumer goods with the use of nanotechnological equipment and consumables from Russian manufacturers” and “Chemical aspects of organic farming”. The first program is aimed at developing students’ competence to carry out analytical determinations of physicochemical indices by methods of thermal and chromatographic analysis, molecular and atomic spectroscopy, electron microscopy, potentiometry, flame photometry, and chemical analysis methods. To achieve this, students acquire the corresponding knowledge (rules for sampling and preparing samples for analytical determinations; principles of the methods of thermal and chromatographic analysis, molecular and atomic spectroscopy, electron microscopy, etc.; the field of their application; the technical characteristics and operation techniques of the corresponding devices; rules for the interpretation of research results and for concluding physicochemical methods of analysis) and skills (sampling and preparing samples of agrosphere objects, raw materials, and food products for the determination of their physicochemical indices, carrying out analytical determinations on special devices, and interpreting the analytical results). The second program, “Chemical aspects of organic farming”, presents a comprehensive scientific and methodological approach to the examination of an organic agricultural enterprise to confirm the quality of “organic” class products. The approach includes a comprehensive assessment of all components of the organic production system “soil–plant–products”. Students gain knowledge about the methods and techniques of the necessary soil examinations and learn to interpret the results. Moreover, they draw conclusions and write down recommendations for improving soil fertility based on physicochemical index data. The program includes only those methods of fertilization and tilling that are permitted in organic farming.

Table 2. Competences based on the chemical knowledge and skills of specialists working in the field of production, processing, and quality control of agricultural products.

| Competences | Skills | Knowledge | Possible Educational Programs for Competence Formation |
|-------------|--------|-----------|-----------------------------------------------------|
| Conduct agrotechnical measures aimed at increasing soil fertility and productivity of cultivated crops. | Conduct sampling of agrosphere objects (soil, water, plants, etc.) for the determination of physical and chemical indices. Assess soil fertility, make recommendations on agrotechnical measures based on the results of the analytical determinations of the physical and chemical indices of soil, water, and plants. Carry out the necessary calculations. Apply fertilizers. | Knowledge of the methods of chemical and physicochemical analysis. Basic knowledge of the fundamental sections of chemistry that are necessary for understanding the foundations of dynamic processes in nature and the technosphere. Quantitative methods describing chemical processes and innovative methods of quantitative information processing. | Bachelor’s disciplines: Inorganic, analytical, physical, colloid, and chemistry; physicochemical analytic methods, the chemistry of biologically active substances, chemicals for plant protection, toxicology of pesticides. Optional: methods for identifying an unknown compound. |
Table 2. Cont.

| Competences | Skills | Knowledge | Possible Educational Programs for Competence Formation |
|-------------|--------|-----------|-------------------------------------------------------|
| Food technologists, technologists for the processing of medicinal and essential oil raw materials, and biotechnologists (Products processing) | Evaluate the introduction of planned changes in the processing technology to improve product quality. | Basic knowledge of the fundamental sections of chemistry that are necessary for understanding and controlling the dynamic processes in nature and the technosphere. | Biotechnology of food raw materials and products of plant and animal origin. |
| Process organic products using processing methods that guarantee environmental integrity and preserve the defining qualitative characteristics of products at all the stages of the production chain. | Control the technological process. | Sampling rules for analytical determinations. | |
| | Conduct sampling of raw materials and food products for the determination of physical and chemical indices at certain stages of the production process. | | |
| | Keep records concerning the laboratory research of raw materials and products. | | |

| Specialists of raw material and finished product quality control laboratories and ecologists (Laboratory research) | Conduct sampling and sample preparation of agrosphere objects (soil, water, plants, etc.), raw materials, and food products for the determination of physical and chemical indicators. | Rules for sampling and preparing the samples for analytical determinations. | Master’s program “Agroecological management, chemical-toxicological and microbiological analysis of agricultural objects” and further education programs. |
| | Perform analytical determinations on devices. | Principles of methods of thermal and chromatographic analysis, molecular and atomic spectroscopy, electron microscopy, etc., the field of their application, the technical characteristics and operation techniques of the corresponding devices. | |
| | Interpret the results of the analytical determinations. | Rules for the interpretation of research results and for concluding physicochemical methods of analysis. | |

3.5. Examples of Implementation of the Green Chemistry Principles in the Educational Process

According to the results of participation in the UI GreenMetric World University Ranking 2021, Russian State Agrarian University named after K.A. Timiryazev became one of the 300 “greenest” universities in the world. Timiryazev Academy is in the top ten among Russian universities. The maximum scores were in the group of indicators “Education and Research”. We propose to consider examples of the inclusion of the principles of green chemistry in the content of the educational process of this agrarian university.

Reduction of production waste to the minimum possible. Students should be taught that they should strive for waste-free agricultural production. For this purpose, the Department of Chemistry of the RSAU—MTAA has been researching an elaboration method for agricultural waste processing. For example, with the help of students, research has been conducted on the processing of flax and hemp straw. The students developed soil formulations for growing seedlings with the addition of flax straw and hemp. In addition, formulations of building materials (tiles and bricks) with the addition of crushed hemp straw were developed (Figure 1).
If possible, substances with minimal toxicity are used by people and the environment. Together with the students, scholars have systematized the information on the physicochemical and toxicological properties of the active substances of preparations approved for use in organic agriculture. The mechanisms of action of the active substances of these drugs were considered.

The environmental safety requirements for the use of mineral fertilizers are constantly increasing. Phosphoric acid purified using organic solvents is often used to obtain phosphate fertilizers. At the Department of Chemistry, cooperating with our students, we researched the most effective method for the purification of phosphoric acid for the subsequent synthesis of phosphate fertilizers. Based on this, a magnesium ammonium phosphate (MgNH₄PO₄) fertilizer was synthesized.

Energy costs should be re-evaluated in terms of savings and environmental impacts and kept to a minimum. Efficient use and heat recovery are some of the most important tasks that humanity has to face today, with both environmental and economic prospects. Therefore, it is difficult to re-evaluate the importance of this issue, especially in the agro-industrial sector. At the Department of Chemistry of our university, we determine the thermodynamic characteristics of biological processes. For this purpose, the department has elaborated a thermo-analytical complex procedure that allows determination of the thermodynamic characteristics of each starting substance and reaction product, quantifying the thermochemical effect of the process and elaborating recommendations for reducing the energy costs of certain biochemical reactions. The research is carried out jointly with our students, who conduct their own projects and are co-authors of scientific articles [45].

The educational and research activities of students are constantly interacting [38,46]. In the basic courses, when studying the section “Thermochemistry”, we include information about the principles of heat management and information about alternative renewable energy sources. This is very important for agriculture since the waste from this industry can be used as an energy source. Cellulose and other types of biomasses, as well as vegetable oils, are an incomplete list of raw materials suitable for these purposes.

The use of catalytic systems and processes. We develop and research or test biochemical process catalysts and plant growth regulators by order of other organizations. The active substances of these drugs affect the dynamics of plant growth and development and the accumulation of certain substances by the plant. For industrial crops such as flax, the purpose of using these preparations is to reduce the amount of lignin and increase the fiber content [47].

Analytical control methods must be applied with sufficient regularity and accuracy. Students learn methods for chemical and instrumental analyses of the corresponding undergraduate disciplines. We have published several handbooks and textbooks on the analysis methods used in agricultural production facilities. In addition, the master’s program “Agroecological management, chemical-toxicalogical, microbiological analysis, and assessment of agricultural objects” described above has been in great demand for more than a decade. An-
alytical instruments and equipment allow students to familiarize themselves with the most innovative methods of analysis: scanning electron microscopy in combination with energy dispersion analysis, near-infrared spectroscopy, thermogravimetry, and other physicochemical methods that allow the rapid analysis of the quality of agricultural commodities (Figure 2).

Express methods are very much in demand when analyzing agricultural objects. With the participation of students, work was carried out, as a result of which a blister-colorimetric method for determining phosphate ions was developed. The determination is carried out in a blister cell containing a mixture of dry reagents in the form of a mixture. This method allows semi-quantitative determination of the phosphorus in various objects without preparation of reagent solutions using a dry mixture packed in a vial or blister. This method can be used to control phosphorus consumption by plants, which in turn makes it possible to rationally introduce nutrients in the form of additional fertilizers [48].

To assess the effectiveness of the work carried out on the formation of students’ competencies based on the principles of green chemistry, an experimental study was conducted. The control group consisted of graduates of an agricultural university, where purposeful work on the introduction of the principles of green chemistry into the educational process was not carried out (46 people).

The experimental group consisted of graduates of the K.A. Timiryazev Russian State Agricultural Academy, whose training was based on the principles of green chemistry (51 people).

Respondents were offered questions and tasks aimed at monitoring the formation of competencies based on the principles of green chemistry.

Table 3 presents the results of the measurements of the level of competence in the field of green chemistry in the control and experimental groups.

Table 3. Results of measurements of the level of competence in the field of green chemistry in the control and experimental groups.

| Competence Level | Control Group, Frequency/% | Experimental Group, Frequency/% |
|------------------|---------------------------|-------------------------------|
| Low              | 38/82.6                   | 27/53                        |
| Average          | 7/15.2                    | 14/27.4                      |
| High             | 1/2.2                     | 10/19.6                      |

A visual description of the results of measuring the level of competence in the field of green chemistry principles is presented in the histogram (Figure 3).
The resulting environmental problems have resulted in several new tasks for agricultural intensification and the chemical competence of specialists of the agro-industrial complex should also be improved. The main advantages of the chemical training system for agrarian students in Russia are the fundamental nature of knowledge, the widespread use of chemical experiments in training, and the involvement of trainees in research work under the guidance of specialists. Chemical training in Russian agrarian universities developed according to the requirements of the agrarian industry in each specific historical period. In the 19th century, the teaching of chemistry was of a classical academic nature. Students acquired fundamental chemical knowledge, and the agrarian specialization of the studied disciplines was minimal. In the twentieth century, the education system was focused on teaching a large number of students and aimed at solving the problems of intensive farming using chemicalization. The resulting environmental problems have resulted in several new tasks for agricultural specialists. The main advantages of the chemical training system for agrarian students in Russia are the fundamental nature of knowledge, the widespread use of chemical experiments in training, and the involvement of trainees in research work under the guidance of the teaching staff.

To overcome the problems associated with the chemicalization of agriculture and intensive use of land resources, the development of environmentally oriented agricultural production and the education of specialists in this industry play a great role. In particular, the chemical competence of specialists of the agro-industrial complex should also be focused on the concept of sustainable development and green technologies.

Modern agriculture needs new, environmentally friendly technologies, which in turn necessitates scientific research and development in this area.

As a statistical criterion on the significance of differences in the level of competence in green chemistry in the control and experimental groups, the \( \chi^2 \) criterion was used. The empirical value of \( \chi^2 \) for the compared samples is 9.1, which is higher than the critical value of \( \chi^2_{0.05} = 5.99 \), which allows us to conclude that the differences in the compared samples are reliable. This allows us to conclude about the effectiveness of the applied pedagogical system for the formation of students’ philosophy of sustainable development based on competence in the field of green chemistry.

4. Discussion

Our study considers in detail chemical competencies expected by the modern agro-industrial complex of Russia for various groups of agricultural specialists. We showed the ways of modernization of the system of teaching chemical disciplines in agricultural universities in order to make it possible to form these competencies. This is a continuation of our previous studies presented in the works [8, 18, 35]. We plan to continue working in this direction, studying the long-term results of the ongoing modernization.

Chemical training in Russian agrarian universities developed according to the requirements of the agrarian industry in each specific historical period. In the 19th century, the teaching of chemistry was of a classical academic nature. Students acquired fundamental chemical knowledge, and the agrarian specialization of the studied disciplines was minimal. In the twentieth century, the education system was focused on teaching a large number of students and aimed at solving the problems of intensive farming using chemicalization. The resulting environmental problems have resulted in several new tasks for agricultural specialists. The empirical value of \( \chi^2 \) for the compared samples is 9.1, which is higher than the critical value of \( \chi^2_{0.05} = 5.99 \), which allows us to conclude that the differences in the compared samples are reliable. This allows us to conclude about the effectiveness of the applied pedagogical system for the formation of students’ philosophy of sustainable development based on competence in the field of green chemistry.

![Figure 3. Results of measuring the level of competence in the field of green chemistry principles.](image-url)
The change in the educational concept of chemical training of a modern agrarian should be systemic in nature and include the following components: ideological (training based on the concept of sustainable development), cognitive (knowledge of green chemistry based on the latest scientific achievements), and activity (experience in practical and research activities to implement the principles of sustainable development in agricultural production).

To achieve this, the university carried out work in several areas. Scientific research was carried out in the field of green chemistry and ecological agriculture: the development of new methods for the use and processing of agricultural waste; the study of sorption properties of soil and plant biomass; the synthesis of substances and the development of new methods of purification of drugs in accordance with the principles of green chemistry; the development of new methods of rapid analysis of substances that can be used for environmental monitoring and other research. During the educational process, attention was paid to the formation of an appropriate worldview and students’ understanding of the value of nature. When building basic courses, the content included information about the principles of green chemistry and new research, including those conducted at our university. Project training and joint work on research with teachers allowed students to gain practical and research experience necessary for the formation of their ability and readiness to cope with professional tasks in the future, guided by the principles of sustainable development and methods of green chemistry. The modernization of the system of chemical training of future farmers is associated with overcoming certain difficulties: it is necessary to seek temporary, material, and intellectual resources. However, the purpose for which it is carried out is undoubtedly worth the effort.

We believe that it would be premature to completely exclude the intensive trajectory of agricultural development at present. However, the search and implementation of cost-effective environmental technologies is already objectively necessary. The ratio of applied technologies should shift toward environmentally oriented ones every year.

Author Contributions: Conceptualization, I.D. and S.B.; methodology, S.B.; software, M.G.; validation, M.G. and A.O.; formal analysis, M.G.; investigation, M.G.; resources, M.G. and A.O.; data curation, M.G.; writing—original draft preparation, M.G. and A.O.; writing—review and editing, M.G. and A.O.; visualization, M.G.; supervision, S.B.; project administration, I.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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